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THE

POPULAR CYCLOPÆDIA OF NATURAL SCIENCE.

BY W. B. CARPENTER, M.D.,

AUTHOR OF "PRINCIPLES OF GENERAL AND COMPARATIVE PHYSIOLOGY," AND
"PRINCIPLES OF HUMAN PHYSIOLOGY."

THE omission of the study of Natural Science from the course of instruction generally followed in this country, appears a neglect of one of the most important means of intellectual discipline and moral improvement which the Almighty has placed within our reach. This study, rightly pursued, has for its object to enable us to read with understanding in that bright volume of Creation, the pages of which are daily and hourly unrolled before us. To every one do "the Heavens declare the glory of God," whilst "the Earth" shows itself "full of His goodness;" but most of all to him who has learned to interpret the wonders they display; and to trace, in the glorious works by which he is surrounded, His power, wisdom, and love.

As a means of intellectual discipline, the study of Natural Science is perhaps second to none. Habits of accurate, discriminating, unprejudiced observation; of cautious reasoning, and of sound judgment; together with a fearless love of Truth, are cultivated by it. Moreover, it has the advantage of interesting the pupil much more than the greater part of the ordinary routine of instruction; and will tend to increase his desire for the attainment of valuable knowledge of any description. Further, at the present day, when Science is constantly furnishing some new and important improvement in those Arts which minister so much to our comfort, and in their turn contribute in various modes to the expansion of the intellect, the practical benefit of a general acquaintance with its principles is sufficiently evident. And whatever portion may be destitute of such direct application, will be found to have uses of its own, in furnishing subjects for the healthy occupation of the thoughts, and objects of pursuit as rational and interesting relaxation.

No works at present before the public appear to be altogether suitable to this purpose; the greater number of *strictly Elementary* Treatises on Natural Science being little else than abridgments of larger works; so that they are much behind the present state of science, and are for the most part but inaccurate copies of one another, executed in a mechanical spirit, and destitute of the striking novelties which scientific research is constantly bringing into view. The Publishers have therefore determined upon bringing out a connected series of Treatises upon the principal departments of Natural Science, designed and executed in accordance with the views above expressed. It is intended that these should all be *founded* upon such knowledge as every person of ordinary capacity possesses, and that the attention of the reader should be directed in the first instance to phenomena of constant occurrence around him; and it is hoped that by a judicious mode of treating the subject, principles may be gradually developed in such a manner as to render them fully comprehensible, and their more extended application thus marked out. "The neglecting to form a proper connection with previously-acquired knowledge; the undervaluing the results of

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PREFACE.

THE want of a good Elementary Treatise on Animal Physiology, has been very greatly felt by those, who have desired to gain a general acquaintance with the Science, or who are entering upon the professional study of it. Indeed, the Author is inclined to believe, that one cause of the almost complete exclusion of the subject from the Educational system of this country,* may be traced to that deficiency. In France it has long been otherwise. A competent knowledge of Animal Physiology and Zoology is there required from every Candidate for University honours; and men of the highest scientific reputation do not think it beneath them, to write elementary books, for the instruction of the beginner.

The general plan of this volume, is the same with that of the Treatise on Physiology, contributed by M. Milne-Edwards, one of the most eminent Naturalists in France, to the "Elementary Course of Natural History," adopted by the French Government as the Text-Book of instruction, in the Colleges connected with the University of Paris. It has the advantage of possessing the same admirable and beautifully-executed series of Illustrations, as those which have been prepared for that work, together with many additions; and a continuation of the same will appear in the Treatise on Zoology, which will be next in order of publication.

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* The University of London have introduced it into the course of study required for the degree of Bachelor of Arts.

In the execution of the details, however, much difference will be found. Whilst careful to omit nothing of any real importance in the work of M. Milne-Edwards, the Author of the present Treatise has found it preferable to give to it a character altogether distinct. The increased size of the volume (which is twice the bulk of the "Anatomie et Physiologie") admitted of the introduction of a large amount of matter, which he believes will be found of great interest and importance; and to have interwoven this with a formal translation of the French Treatise, would have been a much greater labour than the composition of an original work; whilst he ventures to think that its result would have been less satisfactory.

Moreover, there is a considerable difference in the character and objects of the two Treatises. That of M. Milne-Edwards is almost entirely composed of *details;* whilst the Author of the following Volume has been desirous to make it conformable, as far as possible, to the plan of the Series of which it forms part, by combining with these as many *general principles*, as the present state of the Science might warrant his introducing. It has been his constant endeavour to make his Treatise interesting to the intelligent reader, by stating, not only *what is*, but *why it is so*. And if there should seem a needless repetition of certain principles or facts, which are often referred to in the course of the volume, he would observe, that he has found the advantage, in his labours as a Teacher, of frequently bringing these prominently before his Pupils; and that he has therefore considered, that it would be advantageous for his Readers also.

Although this Volume cannot be regarded as an abridgment of either of the Author's larger works (Principles of General and Comparative Physiology, and Principles of Human Physiology,) yet it necessarily contains much in common with them, and may be advantageously used as an introduction to them. He has been desirous of putting forward in this Treatise, such general views only, as are entitled to take rank among the established principles of the science; and he has consequently avoided all reference to many interesting questions, which will be found touched upon in his larger works; and has excluded everything of a controversial character. Acting upon this plan, he has thought it right to include the substance of an Essay of his own, on the action of Cells in the Animal body, which has been characterised by an able Critic as "commanding the highest respect of any one who knows the extreme rarity of the power of systematic and comprehensive generalisation, and can value every approach to the explanation of various and complicated phenomena, by reducing them to a few comparatively simple principles";* whilst he has admitted, to a very limited extent only, the recently promulgated chemical doctrines of Liebig, many of which, although they present a specious probability, will be found to have a very limited application, and to be, in consequence, un-entitled to take rank as established principles.

He has only further to add that, whilst keeping in view the most important practical applications of the Science of Physiology, he has not thought it desirable to pursue these too far; since they constitute the details of the *Art* of Preserving Health, which is founded upon it, and which may be much better studied in a distinct form, when this outline of the Science has been mastered. And, for the same reason, he has adverted but slightly to those inferences, respecting the Infinite Power, Wisdom, and Goodness, of the Great First Cause; which are more obvious, although, perhaps, not really more clear and valid, in this Science, than in any other. Believing, as he does, that these inferences are more satisfactorily founded upon the *principles*, than upon the *facts*, of the Science,—or in other words, upon the general manifestations of *Law* and *Order*, than upon individual instances of Design,—he has thought it the legitimate object of this Treatise, to lay the foundation for them, by developing, so far as might be, the Principles of Physiology; leaving it to a Special Treatise on Natural Theology, to build up the applications.

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* Westminster Review, August, 1843, p. 247.

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INTRODUCTION.

The importance of the study of Animal Physiology, as a branch of General Education, can scarcely be over-estimated; and it is remarkable that it is not more generally appreciated. It might have been supposed that curiosity alone would have led the mind of Man to the eager study of those wonderful actions, by which his body is constructed and maintained; and that a knowledge of those laws on which the due performance of these actions,—in other words, his *health*,—depends, would have been an object of universal pursuit. That it has not hitherto been so, may be attributed to several causes. The very familiarity of the occurrences is one of these. We are much more apt to seek for explanations of phenomena that rarely present themselves, than of those which we daily witness. The Comet excites the curiosity of the vulgar, whilst the movements of the sun, moon, and planets are regarded by them as things of course. We almost daily see vast numbers of animals, of different tribes, in active life around us: their origin, growth, movements, decline, death, and reproduction, are continually taking place under our eyes; and there seems to common apprehension nothing to explain, where everything is so apparent. And of Man, too, the ordinary vital actions are so familiar, that the study of their conditions appears superfluous. To be born, to grow, to be subject to occasional disease, to decline, to die, is his lot in common with other animals; and what knowledge can avail (it may be asked) to avert the doom imposed on him by his Creator?

In reply to this it is sufficient to state, that *millions* annually perish from a neglect of the conditions which Divine wisdom has appointed as requisite for the preservation of the body from fatal disease; and that millions more are constantly suffering pain and weakness, that might have been prevented by a simple attention to those principles, which it is the province of Physiology to unfold. From the moment of his birth, the infant is almost entirely dependent upon the condition in which he is placed, for the future development of his frame; and it depends in great part upon the care with which he is tended, and the knowledge by which that care is guided, whether he shall grow up in health and vigour of body and mind, or become weakly, fretful, and self-willed, a source of constant discomfort to himself and to others; or form one of that vast proportion, whose lot it is to be removed from this world, before infancy has expanded into childhood. The due supply of warmth, food, and air, are the principal points then to be attended to; and on every one of them the greatest errors of management prevail. Thousands and tens of thousands of infants annually perish during the few first days of infancy, from exposure to cold, which their feeble frames are not yet-able to resist; and at a later period, when the infant has greater power of sustaining its own temperature, and is consequently not so liable to suffer from this cause, the seeds of future disease are sown, by inattention to the simple physiological principles, which should regulate its clothing in accordance with the cold or heat of the atmosphere around. Nor is less injury done, by inattention to the due regulation of the diet, as to the quantity and quality of the food, and the times at which it should be given; the rules for which, simple and easy as they are, are continually transgressed through ignorance or carelessness. And, lastly, one of the most fertile sources of infantile disease, is the want of a due supply of pure and wholesome air; the effects of which are sure to manifest themselves in some way or other, though often obscurely and at a remote period. It is physiologically impossible for human beings to grow up in a sound and healthy state of body and mind, in the midst of a close, ill-ventilated atmosphere. Those that are least able to resist its baneful influence, are carried off by the diseases of infancy and childhood; and those whose native vigour of constitution enables them to struggle through these, become the victims, in later years, of diseases which cut short their term of life, or deprive them of a large part of that enjoyment which health alone can bring.

Nor is the effect of these injurious causes confined to infancy, though most strikingly manifested at that period. "The child is father to the man," in body as well as in mind; but the vigorous health of the adult is too often wasted and destroyed by excesses, whether in sensual indulgence, in bodily labour, or in mental exertion, to which the very feeling of buoyancy and energy often acts as the incentive; and the strength which, carefully husbanded and sustained, might have kept the body and mind in activity and enjoyment, to the full amount of its allotted period of "threescore years and ten," is too frequently dissipated in early manhood. Or, again, the want of the necessary conditions for the support of life,—the warmth, food, and air, on which the body depends for sustenance, no less than for its early development,—may cause its early dissolution, even where the individual is guiltless of having impaired its vigour by his own transgressions.

These statements are not theoretical merely: they are based upon facts drawn from observations carried on upon the most extensive scale. Wherever we find the conditions, which the Physiologist asserts to be most favourable to the preservation of the health of the body, most completely fulfilled, there do sickness and mortality least prevail. A few facts will place this subject in a striking light. "The average mortality of infants among rich and poor in this country (and with little variation throughout Europe) is about 1 in every 4½ before the end of the first year of existence.' So directly, however, is infant life influenced by good or bad management, that, about a century ago, the workhouses of London presented the astounding result of 23 deaths in every 24 infants, under the age of one year. For a long time, this frightful devastation was allowed to go on as beyond the reach of human remedy. But when at last an improved system of management was adopted, in consequence of a parliamentary inquiry having taken place, the proportion of deaths was speedily reduced from 2600 to 450 in a year. Here, then, was a total of 2150 instances of loss of life, occurring *yearly* in a single institution, chargeable, not against any unalterable decrees of Providence, as some are disposed to contend as an excuse for their own negligence; but against the ignorance, indifference, or cruelty of man. And what a lesson of vigilance and inquiry ought not such occurrences to convey, when, even now, with all our boasted improvements, *every tenth infant still perishes within a month of its birth!*"*

A recent visitor to the island of St. Kilda, the most northern of the Hebrides, states that 8 out of every 10 children die between the eighth and twelfth day of their existence; in consequence of which terrible mortality, the population of the island is diminishing rather than increasing. This is due, not to anything injurious in the position or atmosphere of the island; for its "air is good, and the water excellent:" but to the "filth in which the inhabitants live, and the noxious effluvia which pervade their houses." The huts are small, low-roofed, and without windows; and are used during the winter as stores for the collection of manure, which is carefully laid out upon the floor, and trodden under foot, till it accumulates to the depth of several feet. The clergyman, who lives exactly as those around him do, in every respect, except as regards the condition of his house, has reared a family of four children, all of whom are well and healthy;

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* Dr. A. Combe on the Physiological and Moral Management of Infancy.

whereas, according to the average mortality around him, at least three out of the four would have been dead within the first fortnight.

One of the most terrible instances ever recorded, of infant mortality resulting from mismanagement, is that which occurred at the end of last century, in the Dublin Foundling Hospital. During the space of 21 years, ending in 1796, out of 10,272 sick children sent to the infirmary, only 45 recovered. In this case, not only deficient ventilation and improper food, but the most criminal treatment, was concerned in the fearful result. The children were not provided with nurses, but were fed by hand; "when they cried and became troublesome, they were dosed with laudanum to keep them still; and the laudanum did succeed in keeping them still, for many of them never awoke." In another institution in Dublin, a most important improvement has been effected by simple attention to cleanliness and ventilation. At the conclusion of 1782, out of 17,650 infants born alive, 2944, or nearly every *sixth* child, died within the first fortnight. By the employment of additional means of ventilating the wards, the number of deaths was speedily reduced to only 419 out of 8033, or about one in 19½, instead of one in every 6; and it has recently been still further diminished. A vast number of facts of a similar kind might be brought together, all proving the same thing. It may be sufficient to add the following statement of the comparative number of deaths of children under five years of age, in London, during successive periods of 20 years; as proving the benefit derived from increased attention to the physiological conditions requisite for health. In the 20 years subsequently to 1730, out of every 100 children born, 74½, or nearly *three out of four*, died before they were five years old. In the succeeding 20 years, the proportion of deaths was reduced to 63 in 100, or less than two-thirds. Between 1770 and 1790, it was only 51½ in 100, or little more than one-half. In the 20 years succeeding 1790, it was further reduced to 41½ in 100, or little more than two-fifths. And between 1810 and 1830, it was no more than 32 in 100, or *less than one-third.* Now although the introduction of Vaccination has unquestionably had a share in reducing the mortality of infants, by mitigating that terrible scourge, the small-pox, yet it will be perceived that the principal diminution took place previously to the time when this came into general use, which was not until the commencement of the present century.

It is not only, however, in diminishing mortality, but in promoting health of body and mind, that attention to the laws of life, as ascertained and applied by the physiologist, proves efficacious. A remarkable and interesting "case in point," is that of the Orphan Asylum in Albany (New York), which was opened in the end of 1829 with about 70 children, the number being subsequently increased to 80. "During the first three years, when an imperfect mode of management was in operation, from 4 to 6 children were constantly on the sick list, and sometimes more; one or two assistant nurses were necessary; the physician was in regular attendance twice or thrice a week; and the deaths amounted in all to between 30 and 40, or about one in every month. At the end of this time, an improved system of diet and general management was adopted; and notwithstanding the disadvantages inseparable from the orphan state of the children, the results were in the highest degree satisfactory. The nursery was soon entirely vacated, and the services of the nurse and physician no longer needed; and for more than two years, *no case of sickness or death took place.* It is also stated that, since the new regimen has been fully adopted, there has been a remarkable increase of health, strength, activity, vivacity, cheerfulness, and contentment, among the children. The change of temper is also very great; they have become less turbulent, irritable, peevish, and discontented; and far more manageable, gentle, peaceable, and kind to each other." *

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* Combe on Infancy.

But this improvement has taken place, not only in regard to infant health, but also in the duration of life among adults. Notwithstanding the common impression, that the men of the present race have sadly degenerated from their ancestors, both as to bodily and mental vigour, a closer examination shows that this is a fallacy; and that we are misled by the pre-eminence attained among their fellows, by men of athletic frames and animal courage, at the time when brute force commanded the chief respect and obedience. In regard to the average duration of life, which may be regarded as affording a tolerably accurate test of bodily vigour, it is unquestionable that a vast improvement has taken place during the last 1800 years. It has been ascertained from historical records, that the average duration of life among the ancient Romans, when compared with that of the English of the present day, was as two to three; that is, out of thirty Romans, as many would have died in a given time, as out of forty-five Englishmen. The term of human life has undergone a considerable increase, even within the last hundred years. Not only has the average mortality of the whole civilised world decreased, in consequence of the greater care and judgment exercised in the treatment of infants and children, but the value of life—that is, the probable number of years which any one may expect to live—has considerably increased. This is proved by the fact, that the tables which were computed seventy or eighty years ago, of the average number of deaths for each year of life, and which served as the basis for the calculations of Insurance companies, are now found to have under-rated the duration of life very considerably; the average number of deaths that would take place in a year, out of one thousand adults of any given age—say thirty-five—being much less at present than it was when those tables were constructed; and a larger proportion, therefore, living to an advanced period of life.

But when we examine the abodes of squalid poverty, and witness the filth, destitution, and wretchedness, which prevail there, we cannot but feel that a yet greater improvement is destined still to result from any measures, that shall convert these into the dwellings of a cheerful, clean, well-fed, thriving population. It appears from the examination of the tables of mortality in France, that the number of deaths per annum, among the poor, is *more than twice as great*, in proportion to the whole number, as it is among those in easy circumstances; and it can scarcely be doubted that the same proportion holds good in this country. If the average duration of life, and freedom from sickness, among the poor, could be raised to the standard which prevails among the higher classes, the whole average mortality of this country would doubtless be reduced, by an amount at least as great as it is already less than that of the most unhealthy countries of Europe. Whilst in England and Scotland, no more than one in fifty-eight now die every year, out of the whole population,—one in forty-five annually die in Germany, one in thirty-nine in France, one in thirty in Turkey and in Italy in general, and one in twenty-eight in the Roman and Venetian states; so that it would almost seem that, the more favourable the climate, the greater carelessness is there respecting the other means that conduce to the preservation of life and health.

It is a principle now universally admitted, that the life or vital actions of no one species of animal can be correctly understood, unless compared with those of other tribes of different conformation. Hence, for the student of Physiology to confine himself to the observation of what takes place in Man alone, would be as absurd as for the Astronomer to restrict himself to the observation of a single planet, or for the Chemist to endeavour to determine the properties of a metal by the study of those of one alone. There is not a single species of animal, that does not present us with a set of facts, which we should never learn but by observing it; and many of the facts ascertained by the observation of the simplest and most common animals, throw great light upon the great object of all our inquiries, the Physiology of Man. For though in him are combined, in a most wonderful and unequalled manner, the various faculties which separately exhibit themselves in various other animals, he is not the most favourable subject for observing their action; for the obvious reason that his machinery (so to speak) is rendered too complex, on account of the multitude of operations it has to perform. So that we often have to look to the lowest and simplest animals, for the explanation of what is obscure in Man; their actions being less numerous, and the conditions which they require being more easily ascertained. Hence, even if we restrict our aims to the investigation of that wonderful series of actions, of which the sum makes up the life of the Human being, we are obliged to refer to a number of other tribes, for the assistance which we gain from the comparison of their structure and operations with his. But if we go further, and aim to build up Physiology as a science, and to place it on the same footing with mechanics, chemistry, or any of those sciences which are founded upon the phenomena of inorganic matter, we must consider Man but as one out of many hundred thousand tribes of living beings, all whose actions have to be studied, the whole history of their lives unveiled, and their minutest structure determined. Until this has been done, Physiology will be deficient in the exactness which it may hope ultimately to possess; but there is much in its recent progress and present state, which encourages the hope, that the time is not far off when its claims to attention will be universally recognised. There is certainly no science which more constantly and forcibly brings before the mind the power, wisdom, and goodness of the Creator. For whilst the astronomer has to seek for the proofs of these attributes in the motions and adjustments of a universe, whose nearest member is at a distance which imagination can scarcely realise, the physiologist finds them in the meanest worm that we tread beneath our feet, or in the humblest zoophyte dashed by the waves upon our shores, no less than in the gigantic whale, or massive elephant. And the wonderful diversity which exists amongst the several tribes of animals, presents us with a continual variety in the mode in which these adjustments are made, that prevents us from ever growing weary in the search.

The diffusion of animal life is only one degree less extensive than that of vegetable existence. As Animals cannot, like Plants, obtain their support directly from the elements around, they cannot maintain life, where life of some kind has not preceded them. But vegetation of the humblest kind is often sufficient to maintain animals of the highest class. Thus the lichen that grows beneath the snows of Lapland is, for many months in the year, the only food of the rein-deer, and thus contributes to the support of human races, which depend almost solely upon this useful animal for their existence. No extremes of temperature in our atmosphere seem inconsistent with animal life. In the little pools formed by the temporary influence of the sun upon the surface of the arctic snows, animalcules have been found in a state of activity; and the tracts of red snow, which frequently cover the surface of arctic and alpine regions for miles in extent, are formed, not merely by the little cryptogamic plant elsewhere described (VEGET. PHYS. §. 48), but by incalculable multitudes of certain species of animalcules, and by the eggs of other kinds. And the ocean of those inhospitable regions is tenanted, not only by the whales and other monsters which we think of as their chief inhabitants, whose massive forms are only to be encountered "few and far between," but by the shoals of smaller fishes, and inferior animals of various kinds upon which they feed, and through the vast fleets of which the mariner sails for many miles together.

On the other hand, even the hottest and most arid portions of the sandy deserts of Africa and Asia, are inhabited by animals of various kinds, provided that vegetables have existed there. The humble and toilsome ants make these their food, and become in turn the prey of the cunning ant-lion and of the agile lizard; and these tyrants are in their turn kept under, by the voracity of the birds which are adapted to prey upon them. The waters of the tropical ocean never acquire any high temperature, owing to the constant interchange which is taking place between them and those of colder regions; but in the hot springs of various parts of the world, we have examples of the compatibility of even the heat of boiling water with the preservation of animal life. Thus in a hot spring at Manilla, which raises the thermometer to 187°, and in another in Barbary, whose usual temperature is 172°, fishes have been seen to flourish. Fishes have been thrown up in very hot water from the crater of a volcano, which, from their lively condition, was apparently their natural residence. Small caterpillars have been found in hot springs of the temperature of 205° ; and small black beetles, which died when placed in cold water, in the hot sulphur baths of Albano. Intestinal worms within the body of a carp have been seen alive after the boiling of the fish for eating; and the inhabitants of some little snail-shells, which seemed to have been dried up within them, have been caused to revive by placing the shells in hot water for the purpose of cleaning them.

The lofty heights of the atmosphere, and the dark and rayless depths of the ocean, are tenanted by animals of beautiful organisation and wonderful powers. Vast flights of butterflies, the emblems of summer and sunshine, may sometimes be seen above the highest peaks of the Alps, almost touching with their fragile wings the hard surface of the never-melting snow. The gigantic condor or vulture of the Andes has been seen to soar on its widely-expanded wings far above the highest peak of Chimborazo, where the barometer would have sunk below ten inches. The existence of marine fishes has been ascertained at a depth of from 500 to 600 fathoms; and in the Artesian well lately sunk in Paris to a depth of about 1800 feet, the water has recently brought up a number of small black fishes, which, being without eyes, seem to have been produced in the depths from which it springs.

The object of the preceding remarks has been, in the first place, to show the importance of the study of Physiology, as leading to the knowledge of those laws, by attention to which the health of the body and mind of man may be most effectually preserved; and, in the second, to show the extent of the field which lies open for cultivation. Their application will be made more apparent in subsequent pages. But as the Author's object is not merely to communicate the results of his own inquiries in the science, but also to stimulate his readers to observe for themselves, and thus to add to its stores, he would add a few remarks on the pleasure and advantage which the intelligent mind may derive, from even a moderate degree of attention, as opportunity serves, to the same pursuit. Every one can do something towards adding to the common stock of information, respecting the structure and habits of the vast number of living beings that people our globe. The immense variety of the objects which come under the investigation of the Physiologist, so far from discouraging the beginner, should have the effect of stimulating his exertions. Of by far the larger part of the organised creation, little is certainly known. Of no single species,—of none of our commonest native animals,—not even of Man himself,—can our knowledge be regarded as anything but imperfect. Of the meanest and commonest tribes, we know perhaps even less than we do of the more elevated and complex; and it cannot be doubted that phenomena of the most surprising nature yet remain to be discovered by patient observation of their actions. It was not until very recently, that the existence of a most extraordinary series of metamorphoses, more wonderful than those of the Insect, has been discovered in the Jelly-fish of our seas, the Barnacles that attach themselves to floating pieces of timber, and the Crabs, Lobsters, and Shrimps of our shores. The very best accounts we have, of the structure, habits, and economy of the lower tribes of animals, have been furnished to us by individuals, who did not think it beneath them to devote many years to the study of a single species; and as there are very few which have been thus fully investigated, there is ample opportunity for every one to suit his own taste in the choice of an object.

And none but those who have tried the experiment, can form an estimate of the pleasure which the study of nature is capable of affording to its votaries. There is a simple pleasure in the acquisition of knowledge, worth to many far more than the acquisition of wealth. There is a pleasure in looking in upon its growing stores, and watching the expansion of the mind which embraces it, far above that which the miser feels in the grovelling contemplation of his hard-sought pelf. There is a pleasure in making it useful to others, comparable at least to that which the man of generous benevolence feels in ministering to their relief with his purse or his sympathy. There is a pleasure in the contemplation of beauty and harmony wherever presented to us; and is not this pleasure increased, when we are made aware,—as in the study of Nature we soon become,—that the sources of them are never-ending, and that our enjoyment of them becomes more intense in proportion to the comprehensiveness of our knowledge? And does not the feeling that we are not looking upon the arts or inventions of a skilful human artificer, but studying the wonders of a Creative design infinitely more skilful, immeasurably heighten all these sources of gratification? If it is not every one who can feel *all* these motives, cannot every one feel the force of *some*?

But it is not only in affording us such interesting objects of regular study, that the bounty of Nature is exhibited. Perhaps it is even more keenly felt by the mind which, harassed by the cares of the world, or vexed by its disappointments, or fatigued by severer studies, seeks refuge in her calm retirement, and allows her sober gladness to exert its cheering and tranquillizing influence on the spirit.

"With tender ministrations, thou, O Nature,
Healest thy wandering and distracted child;
Thou pourest on him thy soft influences,
Thy sunny hues, fair forms, and breathing sweets,
The melody of woods, and winds, and waters,—
Till he relent, and can no more endure
To be a jarring and a dissonant thing
Amidst the general voice and minstrelsy,—
But bursting into tears wins back his way,
His angry spirit healed and harmonized
By the benignant touch of love and mercy."

COLERIDGE.

CHAPTER I.

ON THE VITAL OPERATIONS OF ANIMALS, AND THE INSTRUMENTS BY WHICH THEY ARE PERFORMED.

1. THE general characters of living beings, and their chief distinction from inert matter, have been elsewhere explained (See VEGETABLE PHYSIOLOGY, Chap. I.); and it will not be requisite, therefore, to do more than recapitulate them here.—Living beings, whether PLANTS or ANIMALS, are distinguished from the inert matter which is commonly said to form the MINERAL kingdom, by their peculiarities of *structure* and of *action*. In a living being, no matter how simple its conformation, we find two or more distinct parts or *organs*, adapted for different purposes; thus, in the simple cell which constitutes the entire plant of Red Snow, or the Yeast Fungus (Veg. Phys. §§. 48 and 55), we have a containing membrane which absorbs liquids and gases from the surrounding elements,—a contained fluid of peculiar characters, formed out of these materials,—and a number of minute granules which are to become the germs of new cells. On the other hand, in mineral matter, the same structure and the same properties may prevail through a mass of any size. Hence the structure of living beings is said to be *organised;* whilst that of inert mineral matter is said to be *unorganised* or *inorganic.*

2. Again, living beings are distinguished by their *actions*. Continual change seems an essential part of their character; and the alterations they undergo are not the result of accidental circumstances, but the consequence of their own peculiar properties, and take place with great regularity. Thus if the life of one of the simple plants just mentioned, be attentively watched,

a set of actions will be observed, which may be enumerated briefly as follows. The germ consists of a minute granule, in which no distinction of parts can be observed; but this, by imbibing water and other materials, soon enlarges; and a distinction between the containing and contained parts, the cell-wall and the cavity of the cell, is speedily observed. The enlargement continues, until the full size of the individual is arrived at; and the fluid the cell contains is then observed to have a number of minute granules diffused through it, which resemble the original germ. These granules are at last set free by the bursting of the parent cell, which now ceases to exist, or dies; and its progeny commence life for themselves, and go through the same series of actions as those performed by the parent. These actions are termed *functions;* and their number and variety correspond with the number of different organs existing in the structure. Thus in the simple beings just adverted to, we can only distinguish two sets of operations,—those by which the growth of the parent cell was effected, and those by which the germs of a new generation were produced and set free. The former are termed functions of *nutrition;* and the latter, functions of *reproduction.*

3. But it has been shown that, in the higher Plants, a large number of distinct parts or organs may be observed,—such as the root, stem, leaves, &c.; and that these parts have distinct uses in the economy of the plant. Thus the roots, besides fixing the plant in its position, absorb or suck up liquid from the soil around; and this liquid usually contains, dissolved in it, some of the solid particles which the plant requires as the materials of its growth. The stem has for its office to convey this liquid upwards to the leaves and flowers, where it may be exposed to the air and light. One important function of the leaves is to get rid of a large quantity of this superfluous fluid, by the process termed exhalation; whilst these organs have also the power of absorbing additional fluid, if needed by the plant. Another function of the leaves, is that of taking in an additional most important element, carbon, from the air, by decomposing the carbonic acid it contains; and this being combined in the interior

of their cells with part of the water taken in by the roots, forms the materials by which the tissues of the plant are nourished, and their growth provided for, and whence their peculiar products are supplied. Yet even these most important functions are performed, in the highest plant, as in the lowest, by simple *cells;* for the leaf is but an assemblage of such cells, with a framework or skeleton of harder tissue; and the action of each cell is the same as that performed by the rest. Moreover, when certain products,—such as oil, resin, starch, &c.—are separated from the juices that have been elaborated by the cells of the leaves, and are stored up in particular receptacles, these receptacles are themselves *cells*, the walls of which have the peculiar property of selecting from the juices the materials they are destined to contain.

4. Now all these actions in the Plant are classed under the head of functions of *organic* life, being entirely concerned with the nutrition of the individual. But we have in Animals another series of actions, by which that individual is connected in a peculiar manner with the world around. All animals possess, in however slight a degree, a *consciousness* of what is going on around them;—that is, they are *sensible* to the impressions of external objects. And they all possess, though often to an almost imperceptible amount, the power of acting on objects around them, by *spontaneous motion.* These two functions,—sensibility and the power of spontaneous motion,—being peculiar to animals, are called the functions of *animal* life; and they are sometimes called functions of *relation*, from the peculiar connection they establish between the individual and the world around.

5. The difference between an Animal and a Plant essentially consists in the presence or absence of these powers. Every being which is conscious, in however slight a degree, of its own condition, and of the circumstances affecting it, must be regarded as an animal; and there is reason to believe, that no being possesses such a property, which does not also possess some power of adapting itself to these circumstances by a movement of its body, so as to render its condition more desirable. But it is often difficult to distinguish between a spontaneous movement

of this kind, and those motions which are performed by many plants, without any consciousness or design; and consequently it is not easy to draw the line precisely between the Animal and Vegetable kingdoms. There can be no doubt, however, that such a boundary really exists; although we may not everywhere be able to trace it. We shall find that many animals, though obviously possessing the faculty of giving motion to the individual parts of their bodies, are yet incapable of moving from place to place, being fixed to one spot during all but the earliest period of their lives; and descending still lower, we come to beings which are not only thus rooted, like plants, to the same situation, but which have so little power of moving any part of their mass, and seem to be so destitute of sensibility, that it is difficult to imagine them to possess any distinct consciousness. This is the case, for example, with the Sponge. And yet there is such a resemblance in the structure of the sponge, to that of other beings whose animal character is undoubted, that it is equally difficult to remove it from the animal kingdom; and it is probable that this creature, low as it evidently is in the scale of being, may be endowed with just so much sensibility as may be sufficient to give it a pleasing consciousness of existence, whilst it may be incapable of receiving painful sensations. Its selection of food appears to be no more governed by its *will*, than the same process in vegetables; but it may possess, when satisfied, the same general sense of comfort, as that which we enjoy after a sufficient meal of wholesome food.

6. But, it may be asked, is there nothing in the *structure* of animals, which distinguishes them from plants? And to this it may be replied, that in the higher animals, not only the principal organs, but the greater part of their elementary parts or tissues, are formed upon a plan so entirely different from that which prevails in plants, that there would be no danger of mistaking the one for the other. All the arrangements of the organism or corporeal edifice of the higher animals, are made, as we shall presently find, for the purpose of enabling them to perform, in the most advantageous manner possible, those peculiar functions with which they have been endowed,—to receive

sensations,—to feel, think, and will,—and to move in accordance with the directions of the instinct or the judgment. For these purposes we find a peculiar apparatus, termed the *nervous* system, adapted; this apparatus consists of a vast number of fibres, spread out over the surface of the body, and especially collected in certain parts called *organs of sense* (such as the eye, nose, ear, tongue, lips, and points of the fingers). These have the peculiar property of receiving impressions which are made upon their extremities, and of conveying them to the central masses of nervous matter, (known in the higher animals as the brain and spinal marrow,) where they are communicated to the mind.

7. From these centres, other cords proceed to the various *muscles*, by which the body is moved. These muscles, commonly known as the flesh, are composed of a tissue which has the power of contracting suddenly and forcibly, when peculiar *stimuli* are applied to it. In this respect, it bears a resemblance to the contractile tissues, by which the movements of plants are produced (VEGET. PHYS. §. 420); but it differs from them in being thrown into action, not only by stimuli that are applied directly to itself, but by the action conveyed through the nervous system. Thus, in an animal recently dead, we may excite any muscles to contraction, by sending a current of electricity through the nerves supplying them; and in a living animal we may do the same by simply touching those nerves. But the stimulus which these nerves ordinarily convey, originates in an act of the *mind*, which is connected in some mysterious and inscrutable manner with the central masses of the nervous system. Thus, we *desire* to perform a certain movement or set of movements; this desire leads to an act of *will;* and the will causes a certain stimulus, or motor impulse, to issue from the brain, and travel along the nerves, so as to produce the desired motion by exciting contractions in the muscles that perform it. Or, again, a certain sensation produces an *emotion*, which prompts a certain muscular movement, and may even cause it to take place against the will,—as when a strong sense of the ludicrous produces laughter, in spite of our strong desire (owing to the unfitness of the time and place) to restrain it. The emotion also produces a change in the nervous

centres, which causes a motor impulse to travel along the nerves, and thus calls the muscles into contraction; and it seems to be in the same manner, that those *instinctive* actions are produced, which, although few in adult man when compared with those resulting from his will, predominate in his infant state, and through the whole life of the lower animals (Chap. XIV.). We shall also find that the nervous and muscular systems of animals are concerned in a class of actions with which the mind has no necessary connexion; these actions, such as those of swallowing (§. 195) and breathing (§. 340), having for their object to assist in the performance of the organic functions, and to protect the body from danger.

8. In the higher Animals, then, the presence of this nervous and muscular apparatus is an essential and obvious distinction between their structure and that of plants; and we find that it constitutes a large part of the bulk of the body. Thus the whole interior of the skull of man is occupied by his brain; his limbs are composed of the muscles, and of the bones which support them, and to which they give motion; and it is only in the interior of his trunk, that we find organs corresponding with those which form the whole structure of the Plant. These organs of nutrition have for their main purpose, to supply the wants of the organs of animal life; every exercise of which is accompanied by a certain decay or wear of their structure, and which consequently require to be continually nourished and repaired, by the materials provided by what may be termed the vegetative organs (§. 53). But in the lower tribes of animals, we do not find the animal functions to possess this predominance. In fact, among the many, which are fixed to one spot during nearly their whole lives, and which grow and extend themselves like plants, the movements of the body are but few in number, and trifling as to their variety; these movements are only destined to assist in the performance of the organic functions, as by bringing food to the mouth, and water to the respiratory organs; and the nervous and muscular apparatus by which they are effected, bears so small a proportion to the organs of nutrition, as to seem like a mere appendage to them, and is

sometimes altogether undiscoverable. This is the case, for example, in the lowest kinds of shell-fish, such as the oyster; and in the coral-animals.

9. Hence we perceive, as we descend the animal scale, a nearer and nearer approach to the character of plants; and this we shall find to be the case, not only in the general arrangement of the organs, but also in the nature of the elementary tissues of which they are composed. For in the higher animals, the whole organism is constructed in such a manner, as to admit a free motion in its individual parts. The different portions of the skeleton or hard framework are attached to each other by flexible ligaments, which are adapted to resist a very powerful strain; the muscles are attached to these by fibrous cords or tendons, which, also, can support a vast weight; and the several muscles, and other parts, which need to be connected, but also require a certain power of gliding over one another, are bound together by a very elastic loosely-arranged tissue, consisting of fibres crossing and interlacing in every direction, the interstices between which are filled with fluid. Now to these *fibrous* tissues, there is nothing analogous in plants, because no freedom of motion is required, or even permitted, among their parts. And we find them bearing a less and less proportion to the whole, as we descend the animal scale. On the other hand, we find the various forms of true *cellular* tissue, such as predominate in plants (VEGET. PHYS. Chap. III.), becoming more and more abundant, as we pass from the highest to the lowest, and having more and more important duties to fulfil. But even in the highest Animals, as will hereafter appear, they are the essential instruments of the most important among the organic functions, just as they are in Plants.

10. It is evident, from what has been already remarked as to the peculiar life to which animals are destined, that the mode in which they obtain their nourishment must be very different from that which prevails in the vegetable kingdom. Plants extend their roots through the soil in search of fluid, and spread out their leaves to the air for the purpose of obtaining its carbon; but the animal could not so exist, and be at the same time

endowed with the power of moving from place to place. Hence he requires some other plan of obtaining his food; and this is provided for, in the peculiar character of the food itself, and in the apparatus by which it is taken into his system. We have seen (VEGET. PHYS. Chap. VI.) that Plants will live and thrive, when supplied with the requisite amount of the four elements, oxygen, hydrogen, carbon, and nitrogen, united in the simple forms of water, carbonic acid, and ammonia,—together with certain mineral ingredients; and that hence they can grow at the expense of the elements around, where no living being ever existed previously. But this is not the case with animals. *They* can only exist upon substances, which have been already combined, either by plants or by other animals, into certain peculiar compounds; and thus the whole animal kingdom is directly or indirectly dependent upon the vegetable kingdom for its support; and no animal can exist where a plant has not preceded it.

11. Now, these substances usually exist in a solid form; and since the animal, as well as the plant, is incapable of absorbing nutriment into its body in any but the fluid form, there is need of a preparatory process by which this conversion may be effected. For this purpose, animals are provided with an internal cavity, or *stomach*, in which this conversion is performed. This stomach is nothing else than a bag formed by the prolongation of the external covering of the body into its interior. The cavity serves to hold the food which is introduced into it by the mouth; its walls pour out or secrete a fluid, which acts upon the food in such a manner as to dissolve it; and through its walls are absorbed those portions of the food, which are capable of being applied to the nutrition of the system, while the remainder is cast forth again by the aperture of the bag. Hence the lining membrane of this simple stomach performs the same function as the general surface of the sea weeds, every part of which is endowed with the power of absorbing fluid from the surrounding elements (VEGET. PHYS. §. 102). And as in the higher plants, we find that the function of absorption is specially committed to a set of root-fibres prolonged from the general surface into the soil, so do

we find that in the higher animals it is performed by a set of vessels spread out upon the sides of the digestive cavity or stomach, which take up the nutritious fluid, and carry it to distant parts of the body.

12. Thus it is seen that the possession of a stomach is necessarily connected with the peculiar mode in which Animals are destined to live, and the food on which they are to be supported. By it they are enabled to carry about with them supplies of food, which cannot in general be obtained constantly, but are only to be secured occasionally; and this food they can reduce in it to the fluid form, and thus prepare it for being absorbed. It is obvious that, until it is so absorbed, it is no more within the body of an animal—though contained in its stomach—than is the fluid in the soil which surrounds the roots of plants.

13. Now, this digestive cavity, or stomach, with the organs by which the food is introduced into it, constitute the whole structure of the simplest animals. There seems reason to believe, that many of the lower class of animalcules (§. 136), are little else than single *cells*, differing from those of the red-snow or yeast plant chiefly in this,—that there is an aperture or mouth by which nourishment is introduced into their cavity, so that they do not absorb by their external surface only, but also by their internal,—and that they are furnished with *cilia*, or little hair-like filaments, by the vibration of which, they are moved actively from place to place, and their food conveyed into their mouths. And it is quite certain that animals much more highly organised, are composed of little else than an assemblage of such cells, so arranged as to form a membranous bag, with a mouth, and a circle of arms or tentacula around it, serving to lay hold of and draw in its food.

14. This is the case, for example, with the *Hydra*, or fresh-water polype, a little animal which is very abundant in many of our ponds, and the study of which has been a most fertile source of interest to the microscopic observer. It commonly attaches itself to a stick, straw, or other floating substance, by means of a kind of sucker at its lower extremity; and stretches out

its arms in search of its food, which consists of minute aquatic worms and insects. These are securely laid hold of by one or more of the arms, and are drawn into the mouth, *a*, which leads to the stomach or general cavity of the body, in which they are digested, and from the walls of which the nutritious portions are absorbed. A kind of circulation, or flow of nutritious fluid through channels, appears to take place even in this simple animal, for the conveyance of nourishment to the arms. The portions of the food which are not capable of being digested, are cast out through the mouth; but in the higher polypes, as in all the more complex animals, a second aperture is provided for this purpose.—Now, that the lining membrane of the stomach is nothing else than an inward prolongation of that which covers its surface, is evident from a very curious experiment which has been many times performed upon this little animal, with the same result. It may actually be *turned inside-out*, as we should turn a glove or a stocking; so that the lining of the stomach shall become the external covering, and the external membrane the lining of the stomach; and yet the functions of the animal seem to go on as if they had not been in the least disturbed.

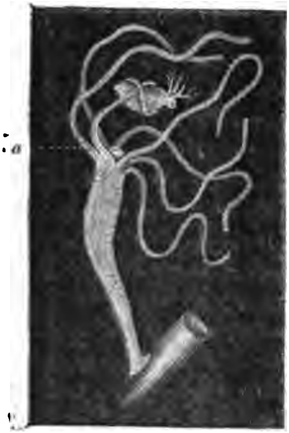

FIG. 1.—HYDRA, OR FRESH-WATER POLYPE.

15. All the chief functions which have been described as taking place in plants, are performed by animals also, besides those which are peculiar to the latter. Thus, the nutriment which has been *absorbed* in the state which may be called the *raw material*, has to be converted into a substance fit for the nourishment of the tissues, and capable of being appropriated by them; this process, resembling the "elaboration of the sap" in plants, is termed *assimilation* (or rendering-like). This assimilated fluid

has to be conveyed into every part of the body, so as to afford it the supply which it needs for its maintenance and growth; and the process by which it is so conveyed is termed the *circulation*. By the same means, the waste or dead matter which is being continually set free in the action of the several organs, particularly of the nerves and muscles, is conveyed away. In order to get rid of this waste, part of it is united with oxygen, and is thrown off by the process of *respiration* or breathing, in the form of carbonic acid and water; whilst part is got rid of in other ways, by the various processes of *excretion*, which separate the injurious substances from the blood, and pour them, in a fluid form, into channels by which they are conveyed out of the body. The process of respiration serves also to introduce a supply of oxygen, which is needed for various purposes in the economy; and it is connected with the maintenance of the animal temperature. Moreover, the blood is conveyed by the circulation to various organs, by which certain fluids are separated, that have particular uses in the economy,—such as the tears, the saliva, the poison of serpents and insects, the odours of many mammalia, &c.; these *secretions*, as they are termed, do not seem to carry off from the blood anything injurious to it, but are destined for other purposes. Lastly, the animal, like the plant, is endowed with the power of *reproduction;* and we shall hereafter find that this process is conducted, in all animals, on a plan closely resembling, in all its essential particulars, that which prevails in the phanerogamic plants.

16. The tissues of animals are composed of a substance, which, in reference to its chemical properties, is nearly the same in all. It has been mentioned, that although most plants require the element nitrogen or azote as one of the materials of their growth, this element does not enter so much into the composition of their own tissue, as it does into that of certain products which they form for the use of animals (VEGET. PHYS. §. 195). Indeed, the organised tissues of plants, if completely separated from the substances they contain, are found to consist of oxygen, hydrogen, and carbon, *only;* these being united in the same proportions as the elements of starch. But all the tissues of animals, if sepa-

ated in like manner from the substances deposited in them, are ound to be composed of the four elements, oxygen, hydrogen, arbon, and nitrogen; and these are for the most part united in he same proportions, as those which form the substance called *lbumen*. This we find in blood, in the white of egg, and in most of the fluids of the animal body; it is the form into which all the substances which contribute to the nourishment of the issues,—such as animal flesh, the gluten of bread, &c.,—are onverted before they are absorbed; and it appears to perform n the animal economy, a part almost precisely corresponding to hat of gum in the vegetable (VEGET. PHYS. §. 329). It is esirable, therefore, to consider its properties before we go urther.

17. Albumen may exist in two states,—the soluble and [illegible]luble. In the animal fluids it exists in its soluble form; [illegible] it is not altered by being dried at a low temperature, but retains its power of being completely dissolved in water. [illegible] a considerable quantity of it exists in a fluid (as in the [illegible] egg), it gives to it a glairy tenacious character; but it is [illegible] When such a fluid is exposed to a temperature [illegible] as in the familiar [illegible] coagulation or setting takes place. [illegible] of boiling an egg. But if the albumen be present in [illegible] the fluid does not form a consistent mass, but [illegible] and this only after being boiled. No trace [illegible] coagulated albumen, which [illegible] in the form of a mass of granules; and in this [illegible] from fibrin—as we shall [illegible] made to coagulate readily [illegible] Albumen may also be made [illegible] nitric acid (aqua-fortis); so that [illegible] be detected in water, by the [illegible] may be a drop or two of nitric acid, [illegible] in the ordinary process of [illegible] milk, which takes place when it is mixed [illegible] the acid contained in the rennet [illegible] in the making of cheese. Now, [illegible] be dissolved again by any [illegible] may be accomplished by

rubbing it in a mortar with a caustic alkali, potass or soda.—We may always distinguish albumen, then, by its peculiar property of coagulating on the application of heat, or on being treated with certain acids.

18. Now it does not appear that albumen can be made use of as the material for the production of tissue, until it has undergone a further process, by which its properties are greatly altered, though the proportions of its elements remain the same or nearly so. This alteration is manifested in its tendency to *spontaneous* coagulation, when withdrawn from the living body; and in the traces of organisation which are presented in the coagulum or clot. We do not meet with this converted albumen, or *fibrin*, in the first products of digestion; but it is gradually formed at the expense of the albumen which these supply; and as it is continually withdrawn by the action of *nutrition*, it is re-formed with equal constancy by the act of *assimilation*. We meet with it in the greatest abundance in the *blood;* and it is that portion of it which causes the coagulation or clotting of the fluid, soon after it is withdrawn from the vessels. In the circulating fluid, the fibrin is completely dissolved,—as completely as the albumen in the white of egg; but no sooner is the fluid at rest, and withdrawn from the contact of a living surface, than it passes into its insoluble form. The coagulum thus produced, however, is far from being as simple as that which is formed of albumen; for it has an evidently fibrous texture; and, when examined under favourable circumstances, a distinct network of fibres, crossing each other in every direction, can be seen in it. Hence we may consider this substance as intermediate between albumen and solid tissue; and the name "chair coulante," or liquid flesh, which has been proposed for it by some French physiologists, very happily expresses its peculiar properties. The act of nutrition seems to consist in the conversion of this material into new cells, fibres, &c., in connection with those previously formed; and the mode in which these new parts originate will be presently considered.

19. Fibrin may be obtained in a separate form, by stirring fresh-drawn blood with a stick, to which it adheres in threads.

of this kind, and those motions which are performed by many plants, without any consciousness or design; and consequently it is not easy to draw the line precisely between the Animal and Vegetable kingdoms. There can be no doubt, however, that such a boundary really exists; although we may not everywhere be able to trace it. We shall find that many animals, though obviously possessing the faculty of giving motion to the individual parts of their bodies, are yet incapable of moving from place to place, being fixed to one spot during all but the earliest period of their lives; and descending still lower, we come to beings which are not only thus rooted, like plants, to the same situation, but which have so little power of moving any part of their mass, and seem to be so destitute of sensibility, that it is difficult to imagine them to possess any distinct consciousness. This is the case, for example, with the Sponge. And yet there is such a resemblance in the structure of the sponge, to that of other beings whose animal character is undoubted, that it is equally difficult to remove it from the animal kingdom; and it is probable that this creature, low as it evidently is in the scale of being, may be endowed with just so much sensibility as may be sufficient to give it a pleasing consciousness of existence, whilst it may be incapable of receiving painful sensations. Its selection of food appears to be no more governed by its *will*, than the same process in vegetables; but it may possess, when satisfied, the same general sense of comfort, as that which we enjoy after a sufficient meal of wholesome food.

6. But, it may be asked, is there nothing in the *structure* of animals, which distinguishes them from plants? And to this it may be replied, that in the higher animals, not only the principal organs, but the greater part of their elementary parts or tissues, are formed upon a plan so entirely different from that which prevails in plants, that there would be no danger of mistaking the one for the other. All the arrangements of the organism or corporeal edifice of the higher animals, are made, as we shall presently find, for the purpose of enabling them to perform, in the most advantageous manner possible, those peculiar functions with which they have been endowed,—to receive

the formation of this compound, which takes place when a piece of skin or other substance largely containing gelatin is immersed in water containing oak-bark, nut-galls, &c. (VEGET. PHYS. §. 364) is the change on which the conversion of skin into leather depends. Now gelatin may be obtained in large quantity, by boiling the skin, bones and cartilages of animals; but it is uncertain whether it always exists in them *as such*, or whether some chemical change is not occasioned by long boiling, which produces gelatin as its result.

21. The number of combining equivalents, or proportionals, of the four elements, which enter into albumen and gelatin respectively, are as follows:—

	OXYGEN.	HYDROGEN.	CARBON.	NITROGEN.
Albumen	14	36	48	6
Gelatin	18	41	48	7½

The actual quantity of each element by weight in 1000 parts of the whole, is,

	OXYGEN.	HYDROGEN.	CARBON.	NITROGEN.
Albumen	213	68	557½	161½
Gelatin	246	70	502	182

Whence it appears that gelatin contains more oxygen and nitrogen (or azote), and less carbon, than albumen. Small quantities of sulphur and phosphorus are found in both fibrin and albumen; but they cannot be traced in gelatin.

Structure of the Primary Tissues.

22. The primary tissues of which the various organs of animals are composed, seem divisible into two classes;—1st, Those which are formed simply by the consolidation of fibrin;—and 2nd, those which, either in their perfect state, or at some period of their formation, are in the condition of *cells*, resembling those of plants.

23. It has been already stated (§. 18) that the clot which is formed by the coagulation of fibrin, even when this takes place *out of* the living body, has more or less of the fibrous character; and this is more distinct, the more slowly and firmly the coagulation takes place. Now, when fibrin is poured out upon a

centres, which causes a motor impulse to travel along the nerves, and thus calls the muscles into contraction; and it seems to be in the same manner, that those *instinctive* actions are produced, which, although few in adult man when compared with those resulting from his will, predominate in his infant state, and through the whole life of the lower animals (Chap. XIV.). We shall also find that the nervous and muscular systems of animals are concerned in a class of actions with which the mind has no necessary connexion; these actions, such as those of swallowing (§. 195) and breathing (§. 340), having for their object to assist in the performance of the organic functions, and to protect the body from danger.

8. In the higher Animals, then, the presence of this nervous and muscular apparatus is an essential and obvious distinction between their structure and that of plants; and we find that it constitutes a large part of the bulk of the body. Thus the whole interior of the skull of man is occupied by his brain; his limbs are composed of the muscles, and of the bones which support them, and to which they give motion; and it is only in the interior of his trunk, that we find organs corresponding with those which form the whole structure of the Plant. These organs of nutrition have for their main purpose, to supply the wants of the organs of animal life; every exercise of which is accompanied by a certain decay or wear of their structure, and which consequently require to be continually nourished and repaired, by the materials provided by what may be termed the vegetative organs (§. 53). But in the lower tribes of animals, we do not find the animal functions to possess this predominance. In fact, among the many, which are fixed to one spot during nearly their whole lives, and which grow and extend themselves like plants, the movements of the body are but few in number, and trifling as to their variety; these movements are only destined to assist in the performance of the organic functions, as by bringing food to the mouth, and water to the respiratory organs; and the nervous and muscular apparatus by which they are effected, bears so small a proportion to the organs of nutrition, as to seem like a mere appendage to them, and is

sometimes altogether undiscoverable. This is the case, for example, in the lowest kinds of shell-fish, such as the oyster; and in the coral-animals.

9. Hence we perceive, as we descend the animal scale, a nearer and nearer approach to the character of plants; and this we shall find to be the case, not only in the general arrangement of the organs, but also in the nature of the elementary tissues of which they are composed. For in the higher animals, the whole organism is constructed in such a manner, as to admit a free motion in its individual parts. The different portions of the skeleton or hard framework are attached to each other by flexible ligaments, which are adapted to resist a very powerful strain; the muscles are attached to these by fibrous cords or tendons, which, also, can support a vast weight; and the several muscles, and other parts, which need to be connected, but also require a certain power of gliding over one another, are bound together by a very elastic loosely-arranged tissue, consisting of fibres crossing and interlacing in every direction, the interstices between which are filled with fluid. Now to these *fibrous* tissues, there is nothing analogous in plants, because no freedom of motion is required, or even permitted, among their parts. And we find them bearing a less and less proportion to the whole, as we descend the animal scale. On the other hand, we find the various forms of true *cellular* tissue, such as predominate in plants (VEGET. PHYS. Chap. III.), becoming more and more abundant, as we pass from the highest to the lowest, and having more and more important duties to fulfil. But even in the highest Animals, as will hereafter appear, they are the essential instruments of the most important among the organic functions, just as they are in Plants.

10. It is evident, from what has been already remarked as to the peculiar life to which animals are destined, that the mode in which they obtain their nourishment must be very different from that which prevails in the vegetable kingdom. Plants extend their roots through the soil in search of fluid, and spread out their leaves to the air for the purpose of obtaining its carbon; but the animal could not so exist, and be at the same time

endowed with the power of moving from place to place. Hence he requires some other plan of obtaining his food; and this is provided for, in the peculiar character of the food itself, and in the apparatus by which it is taken into his system. We have seen (VEGET. PHYS. Chap. VI.) that Plants will live and thrive, when supplied with the requisite amount of the four elements, oxygen, hydrogen, carbon, and nitrogen, united in the simple forms of water, carbonic acid, and ammonia,—together with certain mineral ingredients; and that hence they can grow at the expense of the elements around, where no living being ever existed previously. But this is not the case with animals. *They* can only exist upon substances, which have been already combined, either by plants or by other animals, into certain peculiar compounds; and thus the whole animal kingdom is directly or indirectly dependent upon the vegetable kingdom for its support; and no animal can exist where a plant has not preceded it.

11. Now, these substances usually exist in a solid form; and since the animal, as well as the plant, is incapable of absorbing nutriment into its body in any but the fluid form, there is need of a preparatory process by which this conversion may be effected. For this purpose, animals are provided with an internal cavity, or *stomach*, in which this conversion is performed. This stomach is nothing else than a bag formed by the prolongation of the external covering of the body into its interior. The cavity serves to hold the food which is introduced into it by the mouth; its walls pour out or secrete a fluid, which acts upon the food in such a manner as to dissolve it; and through its walls are absorbed those portions of the food, which are capable of being applied to the nutrition of the system, while the remainder is cast forth again by the aperture of the bag. Hence the lining membrane of this simple stomach performs the same function as the general surface of the sea weeds, every part of which is endowed with the power of absorbing fluid from the surrounding elements (VEGET. PHYS. §. 102). And as in the higher plants, we find that the function of absorption is specially committed to a set of root-fibres prolonged from the general surface into the soil, so do

we find that in the higher animals it is performed by a set of vessels spread out upon the sides of the digestive cavity or stomach, which take up the nutritious fluid, and carry it to distant parts of the body.

12. Thus it is seen that the possession of a stomach is necessarily connected with the peculiar mode in which Animals are destined to live, and the food on which they are to be supported. By it they are enabled to carry about with them supplies of food, which cannot in general be obtained constantly, but are only to be secured occasionally; and this food they can reduce in it to the fluid form, and thus prepare it for being absorbed. It is obvious that, until it is so absorbed, it is no more within the body of an animal—though contained in its stomach—than is the fluid in the soil which surrounds the roots of plants.

13. Now, this digestive cavity, or stomach, with the organs by which the food is introduced into it, constitute the whole structure of the simplest animals. There seems reason to believe, that many of the lower class of animalcules (§. 136), are little else than single *cells*, differing from those of the red-snow or yeast plant chiefly in this,—that there is an aperture or mouth by which nourishment is introduced into their cavity, so that they do not absorb by their external surface only, but also by their internal,—and that they are furnished with *cilia*, or little hair-like filaments, by the vibration of which, they are moved actively from place to place, and their food conveyed into their mouths. And it is quite certain that animals much more highly organised, are composed of little else than an assemblage of such cells, so arranged as to form a membranous bag, with a mouth, and a circle of arms or tentacula around it, serving to lay hold of and draw in its food.

14. This is the case, for example, with the *Hydra*, or fresh-water polype, a little animal which is very abundant in many of our ponds, and the study of which has been a most fertile source of interest to the microscopic observer. It commonly attaches itself to a stick, straw, or other floating substance, by means of a kind of sucker at its lower extremity; and stretches out

its arms in search of its food, which consists of minute aquatic worms and insects. These are securely laid hold of by one or more of the arms, and are drawn into the mouth, *a*, which leads to the stomach or general cavity of the body, in which they are digested, and from the walls of which the nutritious portions are absorbed. A kind of circulation, or flow of nutritious fluid through channels, appears to take place even in this simple animal, for the conveyance of nourishment to the arms. The portions of the food which are not capable of being digested, are cast out through the mouth; but in the higher polypes, as in all the more complex animals, a second aperture is provided for this purpose.—Now, that the lining membrane of the stomach is nothing else than an inward prolongation of that which covers its surface, is evident from a very curious experiment which has been many times performed upon this little animal, with the same result. It may actually be *turned inside-out*, as we should turn a glove or a stocking; so that the lining of the stomach shall become the external covering, and the external membrane the lining of the stomach; and yet the functions of the animal seem to go on as if they had not been in the least disturbed.

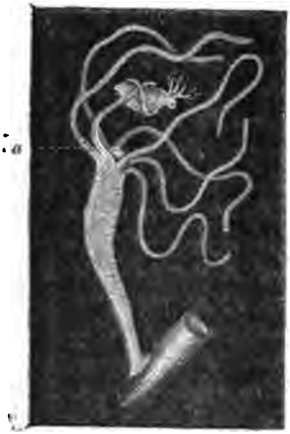

FIG. 1.—HYDRA, OR FRESH-WATER POLYPE.

15. All the chief functions which have been described as taking place in plants, are performed by animals also, besides those which are peculiar to the latter. Thus, the nutriment which has been *absorbed* in the state which may be called the *raw material*, has to be converted into a substance fit for the nourishment of the tissues, and capable of being appropriated by them; this process, resembling the "elaboration of the sap" in plants, is termed *assimilation* (or rendering-like). This assimilated fluid

whole plant, in the lower tribes of the Vegetable kingdom, and all the softer portion in the higher, is composed. It does not form so large a part of the structure of Animals; but we shall find that *their* vital functions are as much dependent upon the agency of cells as are those of plants.

33. In the blood or nutritious fluid, which circulates through the bodies of all but the very lowest animals, there may be seen a number of *colourless cells* floating in the liquid, and carried along in its current. These cells are also to be seen in the nutritious fluid which is taken up in the absorbent vessels (or lacteals) of higher animals, and which is gradually being converted into blood. They contain a number of minute granules, which appear to be the germs of new cells; and it is probable that the life of each parent cell has its appointed period, and that, when that period has elapsed, it bursts (exactly in the manner of the red-snow or yeast plant, VEGET. PHYS. §§. 48 and 55), and sets free these germs, whose development into new cells has already commenced. Now as to the function of these floating cells, a considerable amount of evidence has been brought together to show,* that they are the real agents of the conversion of albumen into fibrin,—a change of the utmost importance in the animal economy.

34. In the blood of all the higher animals, we also find a vast number of minute discs, sometimes round, sometimes oval; these are not colourless, like the former, but contain a red fluid; and to this the colour of the blood is entirely due. These discs, too, are flattened cells; and they also seem to have a fixed term of life, and to be capable of reproducing one another, somewhat in the manner of the last. Their function appears to be that of serving as the *carriers* of oxygen from the lungs, into the tissues which need the supply; and of bringing back the carbonic acid, which is set free in the latter, to be disengaged in the lungs (§.234).

35. The basement membrane just described, is covered, in almost every part, by one or more layers of flattened cells. On that of the skin, these layers are very numerous, and form a con-

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* See a Paper by the author, on the Functions of Cells, in the British and Foreign Medical Review, for January 1843.

tinuous membrane, the *epidermis*, or scarf-skin; this is separated from the true skin, when *raised* by a blister; and it may also be separated after death, by soaking a piece of skin for some time in water. The cells of the outer layers dry up by exposure to the air, and become flat scales; but those of the inner layers, which are kept moist by fluid that is supplied to them from the vessels of the skin, present their usual rounded figure. Now, the outer layers are being continually worn away; and the inner layers are as continually pushed outwards, by the formation of new layers on the surface of the basement membrane. These seem to originate in germs which that membrane contains. The epidermis does not seem to perform any other function, than that of *protection* to the delicate and sensitive surface of the true skin. It undergoes various modifications for this purpose in different animals; whose defences are for the most part formed as appendages to it or alterations of it. Thus in many shells, the exterior layers are formed of cells arranged side by side, and filled with mineral matter; this is the case with the brownish yellow substance which forms nearly the whole shell of Pinna, the outer layers of the Pearl-oyster, and the edges of the outer layers of the common Oyster. The scales of fishes and reptiles, the feathers of birds,—the hair, hoofs, claws, nails, and horns of mammalia,—all possess a structure very similar to that of the epidermis in its nature; and may be regarded as belonging to it.

36. But the layers of cells which cover the internal prolongations of the skin, have very different and more important functions to perform; and in order that these may be understood, it is desirable to explain more fully the nature and offices of the membrane which forms these prolongations. It has been already stated that, in the lowest animals, the membrane which lines the stomach, and that which covers the body, so strongly resemble each other, that one may be made to perform the functions of the other (§. 14); and this is to a certain extent the case even in the highest animals, where, however, each has its own special offices to perform. The *skin* is the part by which chiefly the impressions of external objects are conveyed to us, through the nervous system (§. 6). It is copiously supplied with nerves

over every part; so that there is no portion of the surface, except that which is protected by the nails, on which we cannot feel. For the action of these nerves, a large supply of blood is required. Hence the true skin is principally made up of nerves and blood-vessels, bound together by various kinds of fibrous tissue.

37. On the other hand, it is by means of the membrane lining the digestive cavity, that the functions of digestion and absorption are performed; and it consequently needs a very different structure. It is not supplied with many nerves; and it possesses in health so little sensibility, that we are not aware of the contact of the substances taken in as food, unless they are of an acrid character, or of a temperature very different from that of the body. But it is endowed with the power of secreting the fluids necessary for the solution of the food; and with the power of selecting and absorbing the nutritious products which have been separated from it; and for these purposes it is most copiously supplied with blood-vessels. The same general characters are presented by the membrane that lines the windpipe and air-passages, as well as by several others; and these are all commonly spoken of as *mucous membranes*, on account of the peculiar tenacious secretion, termed *mucus*, by which they are covered, and protected from the irritation that would be otherwise produced by the contact of solid or liquid substances, or even of air, with their free surfaces. When this secretion is checked, which sometimes happens from injuries of the nervous system, the membrane becomes inflamed, and may even be completely destroyed by the diseased action thus occasioned.

38. Mucous membrane may either exist in the condition of a simple expanded surface, covered with one or more layers of flat epithelium cells, which form a kind of pavement to it; or it may have a much more complex arrangement, by which its surface is greatly increased. The *simple* mucous membrane, such as that which lines the nose and air-passages, is found, for the most part, where no absorption has to be performed, and where only a moderate amount of secretion is necessary. But where it is to absorb as well as to secrete, it is usually *involuted* or folded upon itself, in such a manner as to form a series of little

projections, and also a number of minute pits. These projections sometimes have the form of long folds; in other instances they are narrow filaments, crowded together so as almost to resemble the *pile* of velvet. In either case, the absorbent surface is vastly increased; but chiefly so by these filaments, which are termed *villi*, and act as so many little rootlets. On the other hand, it is in the pits or *follicles* that the production of the fluid, which is to be separated or secreted from the blood, chiefly takes place.

39. The whole surface of every mucous membrane, whether simple or involuted, is usually covered with cells, resembling those of the epidermis, but never dried up into scales; and the layer formed by these cells, which sometimes adhere into a continuous membrane, whilst in other instances they readily separate from each other, is called the *epithelium*. This epithelium is frequently being cast off, like the epidermis; especially from the parts that are most concerned in secretion: and it is as continually being replaced, by the development of new cells from germs contained in the basement membrane, at the expense of fluid that transudes it from the blood-vessels copiously distributed beneath. Not only are the flat expanded surfaces of the mucous membrane covered with epithelium cells, but the villi also are sheathed by them; and the secreting follicles are lined by the same. It would appear, however, that the epithelium cells of the *villi* have the *protection* of their delicate surface for their chief purpose; and

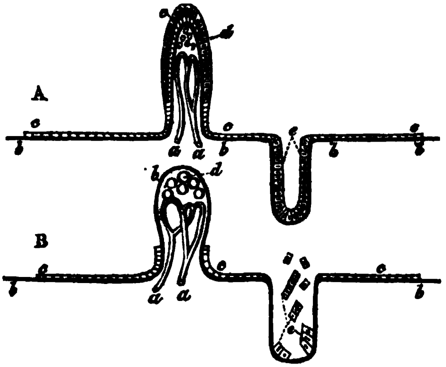

FIG. 2.

Diagram representing the MUCOUS MEMBRANE OF THE INTESTINAL CANAL; A, in the intervals of digestion; B, during digestion; *a*, *a*, absorbent vessels; *b*, *b*, basement membrane; *c*, *c*, epithelium cells; *d*, *d*, absorbent cells of villus; *e*, *e*, secreting cells of follicle.

that they fall off when these minute but most important organs are performing their function of selecting and absorbing the nutritious elements of the food,—being replaced again in the time that elapses before the next digestion. On the other hand, it seems probable that the epithelium cells of the *follicles* are the real agents in the *secreting* process;—that they draw from the blood, as materials for their own growth, certain elements contained in it;—and that, when mature, they fall off, and discharge these substances as the product of secretion, giving place to a fresh crop or generation of cells, which go through a series of changes precisely similar to the preceding.

40. Now these follicles are the simplest types or examples of all the *glandular* structures, by which certain products are separated from the blood, some to be cast forth from the body as unfit to be retained in it; and some to answer particular purposes in the system (§. 15). In all of them, the structure ultimately consists of such follicles, sometimes however swollen into rounded vesicles, and sometimes extended into long and narrow tubes. Each follicle, vesicle, or tube, is composed of a layer of basement membrane, lined with epithelium cells, and surrounded on the outside with minutely distributed blood-vessels; and it seems to be by the peculiar powers of these cells, that the products of the secreting action, whether bile, saliva, fatty matter, or gastric fluid, are formed. Hence we see that the act of *secretion* is, in animals as in plants, really performed by cells. It is necessary to bear in mind, however, that a simple *transudation* of the watery parts of the blood may take place without any proper secreting action, in the dead as in the living body; and it is in this manner that the serous fluid of areolar tissue and serous membrane is poured out.

41. Recent discoveries enable us to go further, and to say that the *selective absorption* of nutritious matter seems to be performed by the same agency. It is necessary to distinguish the absorption by the villi of mucous membrane, which are the roots, as it were, of the vessels that take up the nutriment, from the mere *imbibition* (or drinking in) of fluid, which may take place through any thin and soft animal tissue. We shall find hereafter, that water

and *any* substances completely dissolved in it, which do not render it viscid, may be thus absorbed by the blood-vessels; but that the *villi* seem to have the peculiar property of selecting *nutritive* substances only, and of conveying these into the vessels adapted to carry them into the circulation (§. 218). This they appear to accomplish by means of a set of cells developed at their extremities for this purpose, every time that the process takes place. In the intervals of the digestive action, only a few granules, which appear to be cell-germs, can be seen at the end of the villus (Fig. 2. A, *d*); but when absorption is taking place, the protective epithelium falls off, and a number of large round cells, filled with a milky fluid, are seen to have been developed at the extremity of each villus (Fig. 2. B, *d*). These cells lie very close to the loops that form the commencement of the absorbent vessels; and when they have become filled with fluid, they either burst or dissolve away, and yield their contents to those. This process is repeated every time that the absorption of this peculiar fluid, termed *chyle*, takes place.

42. Thus it will be seen, that these apparently simple and insignificant bodies, *cells*, are the real agents in the two most important processes in the nutritive operations,—the *absorption* of nutritive matter, and the *excretion* of substances that are unfit to be retained in the system. We shall hereafter see that the latter is even the more constantly important of the two; for that an animal may live for some time without food, whilst it is rapidly destroyed if its blood be not purified from the matter that is destined to be excreted. There is something extremely mysterious in the performance of these different operations, by instruments that appear so simple, and which so strongly resemble each other. There would not seem any obvious reason, why one set of cells should thus minister to absorption, and another to excretion. Perhaps, however, it may be partly explained from their respective situations. The absorbent cells are situated in the substance of the villus, beneath its covering of basement membrane; hence, when they burst or dissolve, their contents are not set free, but they are delivered to the vessels in their neighbourhood, by which they are imbibed. On the other hand, the secreting cells cover the free surface of

the basement membrane; and when they liberate their contents, these are cast into the tube or canal whose walls they help to form, and are thus conveyed away. In the fatty tissue, we have an example of cells, endowed with a similar power of secretion, but, through their difference of situation, remaining to form part of the regular structure of the body (§. 44). But of the reason why one secreting cell should separate from the blood a certain product, and another should draw off a product entirely different, we can give no account whatever.

43. We have cases exactly parallel in the vegetable, however; for in the same plant we may find one set of cells secreting (or drawing from the circulating fluid into their own cavities) a fixed oil—another set, a volatile oil—another set, starch—another set, colouring matter—and so on. In the tissue of a parti-coloured flower, we observe cells lying side by side, and apparently under precisely the same circumstances, but which secrete or produce different kinds of colouring matter, so that one (for example) shall be blue, and the other yellow. Or if we go to the opposite extremity of the scale, we find one species of plants, composed of separate cells only, adapted to live upon any cold damp surface, and to obtain its nutriment from the air and moisture around; whilst another plant, also consisting of separate cells, can only live and vegetate, when supplied with animal or vegetable matter in a state of change or decay.* Of the reason of the respective peculiarities of these cells, no account whatever can be given; and we are consequently as much in the dark respecting their cause, as we are in regard to the reason of the peculiar operation of cells in the animal economy. But it is an important and interesting step in the science of Physiology, to be able to show that, although the structure and mode of life of Animals appear so different from those of Plants, the manner in which those functions that are common to both are performed, is *so precisely the same.*

44. In the bodies of the higher animals, there are few organs of whose tissue cells form a permanent part; except the epidermis and its appendages, and the epithelium. In almost every part

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* See the account of the *Red Snow* and *Yeast Plant,* in VEGET. PHYSIOL. §§. 48 and 55.

of the body, however, we find oily matter or fat deposited in the areolar tissue. It does not lie freely there, in the meshes of that tissue; for if it did, it would not be confined to particular spots, but would find its way from one part of the body to another (§. 24). The fatty tissue is distinct, as well as the fatty matter itself; for it is composed of minute cells or vesicles, having no communication with each other, but lying side by side in the meshes of the areolar tissue, which serves to hold them together, and through which also the blood-vessels find their way to them. From the fluid in these vessels, the fatty matter is separated in the first place; and it is prevented from making its way through the very thin walls of the cells, by the simple expedient of keeping these constantly moist with a watery fluid, the blood.* The blood-vessels have also the power of taking back the fatty matter again into the circulation, when it is wanted for other purposes in the economy. These deposites of fatty matter answer several important objects. They often assist the action of moving parts, by giving them support without interfering with their free motions; thus the eye rests on a sort of cushion of fat, on which it can freely turn, and through which the muscles pass that keep it in play. It also affords, by its power of resisting the passage of heat, a warm covering to animals that are destined to live in cold climates; and it is in these that we find it accumulated to the largest amount. Further, being deposited when nourishment is abundant, it serves as a store which may be taken back into the system, and made use of in time of need. The causes which peculiarly contribute to the production of fat will be considered hereafter (Chap. III.)

45. Another tissue of which cells form the principal part, is that termed *cartilage* or gristle. Its simplest state is that of a mass of firm gelatinous substance, through which are scattered a number of cells, at a greater or less distance from one another. In the gelatinous substance itself, no trace of structure can be seen, in the simple cellular cartilages, such as those which cover

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* Thus oil will not pass into blotting-paper, if this have been previously moistened with water.

the ends of the bones, where they glide over one another so as to form movable joints. But in cartilages which have to resist not only pressure but also extension or strain, we find the space between the cells partly occupied by fibres, which resemble those of ligaments; and such are termed fibro-cartilages. They are found in man between the vertebræ of which the spinal column is made up (§. 63); and also uniting the bones of the pelvis (§. 85.) Sometimes, where elasticity is required, the fibres are those of the yellow fibrous tissue (§. 29); this is the case with the cartilage which forms the external ear. Cartilage is not penetrated by blood-vessels; at least in its natural state. The blood is brought to its surface, by a set of vessels which bulge out into dilatations or swellings upon it, so that a large quantity of fluid is spread out over the cartilage, only separated from it by the thin walls of the vessels; and it appears that this fluid, or so much of it as is required, is absorbed by the nearest cells, and transmitted by them to the cells in the interior, so that the whole substance is nourished. This is precisely the mode in which the interior of the large sea-weeds (whose tissue consists of cells imbedded in a gelatinous substance, and therefore bears a close resemblance to animal cartilage) obtains its nourishment from the surrounding fluid. (VEGET. PHYS. §. 102).

46. The permanent cartilages seem to undergo very little change from time to time. Their *wear* is slow; and, being purely mechanical, it is confined to the surface. It is replaced by the materials absorbed from the blood, which are employed in the development of new cells,—sometimes within the old ones, sometimes in the space between them. When a portion of cartilage has been destroyed, however, by disease or injury, it is not renewed by true cartilaginous structure, but by what seems a condensed areolar tissue. Although cartilage does not usually contain vessels, yet these may be rapidly developed in its substance, by a process which will be described hereafter (Chap. VII.), when it becomes inflamed. This may be often *seen* to take place. The front of the eye is formed by a transparent cartilage, bulging like a watch-glass; which is termed the *cornea* (Chap. XI.) This substance is properly nourished only

by vessels that bring blood to its edge, where it is connected with the tough membrane that forms the *white* of the eye. But when the cornea becomes inflamed, minute vessels may be seen to spread over it, proceeding from its circular edge towards its centre; and at last some of these often become of considerable size. Under proper treatment, however, these vessels gradually shrink and disappear; and the cornea becomes nearly as transparent as before.

47. Many parts exist in the state of cartilage in the young animal, which are afterwards to become bone; and in fact we may say that *all* bones have their origin in a cartilaginous structure. The transformation is a very curious one, and is not yet properly understood; but the nature of the bony structure is easily explained. When we cut through a fully formed bone, such as that of the thigh, we find that the *shaft* or lengthened portion is a hollow cylinder; of which the walls are formed by what appears to be solid bone; whilst the interior is filled, in the living state, by an oily substance laid up in cells, and termed *marrow*. Towards the extremities, however, the structure of bone is very different. The outside wall becomes thinner; and the interior, instead of forming one large cavity, is divided into a vast number of small chambers, like those of areolar tissue, by their bony partitions, which cross each other in every direction. These chambers are filled with marrow, like the central cavity, with which they communicate. In the flat bones, moreover, —such as those of the head,—we find that the two surfaces are composed of dense plates of bone, like that which forms the shaft of the long bones; but that between them there is a layer of this areolar structure, filled in like manner with marrow. But when we examine with the microscope a thin section of even the densest bony matter, we find it traversed by a network of minute canals, all of which proceed from the central cavity, and are filled, like it, with marrow. These canals usually run, in the shafts of long bones, in the direction of their length; and are connected, every here and there, by cross branches. They are termed the Haversian canals, after the name of their discoverer, Havers. The lining membrane of the large central cavity is

copiously supplied with blood-vessels; and this sends off prolongations into the areolæ at the extremities of the bone, and into the Haversian canals. Thus blood is conveyed into the interior of the bone; but no vessels can be traced absolutely into its texture, so that all the spaces which lie between the Haversian canals are as destitute of vessels as is healthy cartilage. These spaces are provided with nutriment by the following very remarkable arrangement.

48. When we cut across the shaft of a long bone, and examine a thin section with a microscope, we of course see the open extremities of the Haversian canals (Fig. 3, *a*); just as we see the cut ends of the ducts and vessels of wood, when we make a transverse section of a stem (VEGET. PHYS. §. 129). Around each of these apertures, the bony matter is arranged in concentric rings, which are marked out and divided by circles of little dark spots; and when these spots are examined with a higher power, it is seen that they are small flattened cavities, from which proceed a number of extremely minute tubules (A). These tubules pass out from the two flat sides of each cavity; one set passes inwards, towards the centre of the ring, and the other outwards towards the ring that next surrounds them. These minute tubuli, which are far smaller than the smallest blood-vessels, may thus be traced into every part of the substance of the bone; and

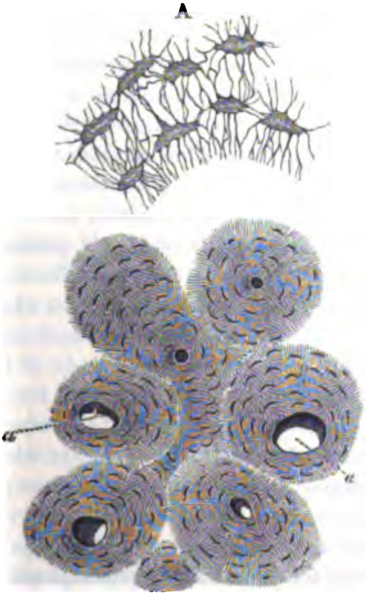

FIG. 3.

SECTION OF BONE, showing the concentric rings round *a a*, the Haversian canals. At A are seen some of the cavities with their radiating tubes, more highly magnified.

those proceeding from different rings are so connected with each other, that a communication is established between the innermost and the outermost circles. The tubuli which open upon the sides of the Haversian canals, are thus enabled to take up the nourishment with which they are supplied by the blood-vessels, and to transmit it to the outer circles, or those furthest removed from those vessels; and in this manner, a much more active nutrition takes place in bone than that which is performed in cartilage. It has been proved by various experiments, that the substance of bone is undergoing continual change; and it is owing to the comparative activity of its nutritive processes, that bone is so readily and perfectly repaired, when it has been broken by violence, or injured by disease.

49. But the peculiarity of bone consists, not so much in this remarkable arrangement of its organic structure, as in its solidity and firmness. This is given to it by the deposition of a large quantity of mineral matter in the cartilaginous portion of its tissue. Such a deposition sometimes takes place in ordinary cartilages, especially in old persons; thus the cartilages which unite the ribs to the breast-bone are often found to possess an almost bony hardness in persons who are advanced in life, although the organic structure is not changed. The mineral matter of bones consists almost entirely of two compounds of *lime;* the carbonate, with which we are familiar in the form of limestone and chalk; and the phosphate, which is seldom found as an ingredient of rocks or soils, except where it has been derived from animal remains. The latter greatly predominates, at least in the bones of the higher animals. We may easily separate the animal and the mineral portions of the bony tissue. If we soak a small bone for some time in muriatic acid (spirit of salt) much diluted with water, the compounds of lime are entirely removed from it, and the cartilaginous substance remains; the latter is now quite flexible, and almost transparent, so that the distribution of its vessels (if they have been previously injected with colouring matter) may be distinctly seen. On the other hand, if we subject a bone to strong heat, the animal portion will be burnt out, and the earthy matter will remain. The form of the bone will

be still retained; but the cohesion between the earthy particles is so slight, that the least touch will break them asunder. Thus we see that the *hardness* of bone, or power of resisting pressure, is given by the earthy matter; whilst its *tenacity*, or power of holding together, depends upon the animal portion. The amount of mineral matter in the bones increases with the age; thus in the child it forms about half the weight of the bone, in the adult four-fifths, and in the old person seven-eighths.

50. Of the conversion of cartilage into bone, it may be sufficient to say, that the Haversian canals, and the areolæ of the spongy texture, seem to be formed by the union of a considerable number of cartilage-cells, which are much increased in number, and become arranged in rows or in clusters. By their union, a tube is formed (in the same manner as the *ducts* of plants originate in cells which break down into one another, VEGET. PHYS. §. 82,) in the one case; and a little chamber in the other. These tubes and chambers communicate with each other, and with the central cavity; and from the latter, vessels are prolonged upon their lining membrane, from which the bony matter is deposited. The peculiar cavities and tubuli of bone seem to be spaces left, in which this deposit is not laid down.

51. The conversion of cartilage into bone is going on for some time after birth, as well as previously. In the long bones, it commences at several distinct points, being those near which the vessels enter, and from which they spread out or radiate. And the different portions first ossified or converted into bone, are not firmly united to each other until sometime afterwards. It is curious to observe that, in Reptiles and Fishes, many parts which are thus united in the higher animals, remain permanently seperate. And there is a large group of Fishes, in which the skeleton retains the cartilaginous character throughout life; a certain quantity of mineral matter being deposited in the cartilage, but its conversion into bony structure never taking place. In a few, not even a firm cartilage is produced; and all the trace of a skeleton is a tube surrounding the brain and spinal marrow, (§. 64), formed of a mass of hexagonal cells, resembling those of the pith of plants. Such a tube precedes the formation of the system of bones, which takes its place in the higher animals.

52. The various tubes and vessels through which blood and other fluids are conveyed, have their origin in cells, precisely as they have in plants. In the lowest animals no such tubes exist; and the same is the case even with the highest, in their early condition. For these, as will be shown hereafter (Chap. v.), consist but of a mass of cells, of which some afterwards become cartilage, some are converted into bone, some into muscle, and so on; whilst some break down into each other, so as to form the tubes required for the conveyance of fluids from one part of the system to another, just as they are in plants. Of these tubes some are straight and single, like the ducts in which the sap ascends; whilst others form a network, like that in which the elaborated sap circulates in plants (VEGET. PHYS. §. 87).

53. We have now completed our general survey of the principal tissues of animals; excluding, however, the nervous and muscular, which depart more widely from the characters we have been considering, and which it will be preferable to describe when treating particularly of their functions (Chaps. x. and xii.). The mode in which these are severally formed will be explained hereafter; and at present it will be enough to say that, as every organised being has its allotted term of life, which may be prolonged or shortened to a certain degree, according to circumstances, so every portion of its fabric appears destined to last only for a certain time, and to cease to exist as soon as it has performed its peculiar office. Thus the cells which float separately in the blood seem to be continually undergoing a change, —dying, and giving birth to others. We have seen that the cells of the epithelium and the epidermis are also being constantly thrown off and renewed. The duration of the cells of fat and cartilage appears to be much greater; in fact, we have no precise knowledge of their term of life. But that of the muscular and nervous tissues seems to depend almost entirely on the use that is made of them. When an animal is quite inactive, these require but very little nutrition; but every one of its movements, in which a certain expenditure of muscular and nervous power takes place, seems to involve the death and re-formation of a certain portion of these tissues; for we find that any animal in a state of activity requires a far greater amount of food, and sets

free by excretion a far larger quantity of dead matter, than while it is continuing in a state of rest. Thus it is that Animals expend so large an amount of nutritive matter, not in the extension of their own structure as Vegetables do, but in the performance of those movements which are peculiar to themselves.

54. From the foregoing statements we may justly say,—however startling the assertion may seem,—that death and decay are continually going on in every living animal body, and are essential to the activity of its functions. Many animals are capable of being reduced to a state of complete torpidity, without the loss of their vitality; so that all their actions are renewed, when they are again placed in the requisite conditions. Some are reduced to this state by cold; others by dryness. Amongst the most remarkable examples of this are the *Wheel-Animalcules* (§. 117); some species of which may be completely dried up, and may be even exposed to a temperature much exceeding that of boiling water, without losing the power of recovery when again moistened. An animal in this state strongly resembles a seed, which is prevented from germinating, by being kept at a moderate temperature, and excluded from the influence of air and moisture. (VEGET. PHYS. §. 446.) Instances have been recorded, in which seeds have been thus preserved for a known period of more than 2000 years; and there are others in which the period was probably much longer. There are no positive facts which enable us to say, how long an animal may remain in a similar condition; but it is well known that revival has often taken place, after the body has been frozen or dried up for several years; and there seems no reason why it should not occur after many times that period. It is to be remembered that this is a condition, in which the decay of even dead animal matter is resisted. Frozen animals are brought from the remotest parts of the Russian empire, to be sold as food in the markets of Petersburgh; and their flesh, when thawed, is as good as ever. Again, meat, dried and pounded, forms the staple food of the North American hunters, by whom it is kept for weeks or months without change. Even in the moist state, animal and vegetable substances may be perfectly preserved for years, if

they are completely excluded from the air. This is the plan now adopted in victualling ships for long voyages. The substances, partially cooked, are put into tin vessels; these are completely filled with gravy, &c.; and they are soldered down whilst the contents are hot. Thus we see that the decomposition of the animal body is not a necessary consequence of its death; whilst it is in fact continually going on during its life.

55. In what then, it may be asked, does the peculiar condition of a *living* body, as distinguished from a dead one, consist? To answer this question, it is necessary to consider the body as a *whole*, and as made up of several *parts*. Each of these parts has its own independent vitality; that is, it has its own peculiar properties, which depend upon the mode in which its elements are combined and arranged (VEGET. PHYS. §. 8); and these it will continue to exercise, as long as it is supplied with the necessary conditions. Thus the secreting cells of the epithelium require a supply of blood, both for their own growth, and for the formation of their peculiar products. The muscular tissue cannot act without a supply of oxygen, and this is conveyed to it by the blood. All the tissues possessing peculiar vital properties, are in like manner dependent upon the blood or nutritive fluid for the continued exercise of these. But after the circulation of the blood has ceased, so that the *body* is commonly said to be *dead*, its *parts* may remain *alive* for a certain time, and may perform their functions, so long as they are supplied with the necessary materials. Thus, various secretions, the growth of hair, and muscular movements, have been observed to take place in dead bodies. But they cannot continue, because the necessary conditions are withheld by the stoppage of the circulation,—a function which thus binds, as it were, into one whole, the scattered elements, and causes the different operations to minister to one another.

56. The *death* of the body, therefore, is said to take place when its circulation *permanently* ceases; since on this circulation all its functions depend. But, as we have just seen, the separate parts may retain their vitality for some time longer,—some of them, indeed, until they are actually beginning to become putrid.

And, on the other hand, the circulation may cease *for a time*, as in fainting or temporary suffocation among the higher animals, or in torpidity among the lower. The time is short, however, during which it can be thus suspended among warm-blooded animals; because their tissues very soon begin to undergo a destructive change. And the reason why it may be almost indefinitely prolonged, in those animals which can submit to being frozen or dried up, appears to be simply this,—that this treatment prevents that destructive change from taking place.

57. Hence, *life* is not (as has sometimes been asserted), the condition in which decay is resisted; but the condition in which, by the wonderful adaptation and mutual harmony of the operations of the different parts,—a harmony which *could* only proceed from the mind of an All-powerful and All-wise Being,—they are all made to unite to one common end, the maintenance of the structure in a condition fit for the performance of its proper actions. So long as all these actions go on with regularity and completeness, so long the whole body lives; but if any one of the more important among them be interrupted, the stoppage of the whole must be the result. If we could imagine a steam-engine capable not only of constantly supplying itself with water and fuel, but also of repairing its own wear and tear of materials, we should have some notion, by analogy, of what may be termed the *physical* functions of the animal body. But it must be borne in mind, that the body which these functions are destined to maintain, is but the instrument, in Animals, of a higher set of operations, those of the *mind;* to which no actions performed by any piece of mechanism constructed by Man, or even by those most refined and beautiful fabrics of which the Vegetable kingdom is composed, bear the slightest resemblance. Of the mode in which the *mind* is connected with the *body*, and uses it as its instrument, we have not, and probably never shall possess in our present state of being, the most distant idea.

CHAPTER II.

GENERAL VIEW OF THE ANIMAL KINGDOM.

59. When we examine the Animal Kingdom as a whole, it is easy to distinguish in it *four* general plans or *types* of structure, by which, with almost infinite variations in detail, the formation of the several beings that compose it has been guided. As specimens of these four plans or types, we may name four animals which are familiar to almost every one,—the Dog, the Lobster, the Slug, and the Star-fish.

60. The differences by which these types are distinguished, are manifested in the arrangement of the different organs of the body; and particularly in the form of the nervous system and its instruments. It has been already stated (§. 4) that the power of *feeling*, and of *spontaneous motion*, is that which peculiarly distinguishes the Animal from the Plant; and as these powers are possessed in very different degrees, and exercised in very different modes, by the various tribes of animals,—whilst the operations of nutrition are performed, as in plants, in a much more uniform manner,—they afford us a satisfactory means of separating these tribes from one another. For the nervous system is the organ to which these powers are due; and we find it presenting forms so different, in the four great divisions already alluded to, that we can at once distinguish them by this alone, even where (as sometimes happens) there may be such a blending, in a particular animal, of the *general* characters of two of them, as to lead us to hesitate in assigning its place in the animal kingdom.

61. But it is not only in the form and arrangement of the parts of the nervous system, that we find such important dif-

ferences; for there are other organs connected with the powers of sensation and motion, the arrangement of which also exhibits corresponding variations. Thus the power of motion is dependent upon the *muscles*, which are called into action by the nervous system; and these cannot act with any force, unless they are attached to hard parts, connected together by joints, so as to form a *skeleton*. Now this skeleton sometimes consists of *bones*, which are clothed by the muscles, as in the dog. Sometimes it consists of a jointed *shell*, enclosing the muscles, as in the lobster. And sometimes it is altogether absent; and the muscles, having no firm points of attachment, act slowly and with little power, as in the slug. In regard to the arrangement of the organs of special sense, also,—those of sight, hearing, smell, and taste,—there is a corresponding variation. In the dog and the lobster, they are set upon a prominent part of the body, in the neighbourhood of the mouth; and this is termed the *head*. In the slug, too, this is also the case; but in the oyster, an animal of lower organisation, belonging to the same division, there is no head, and the few organs of sense which it possesses are almost buried (as it were) in the mass of the body. Lastly, in the star-fish, there is a similar absence of anything resembling a head; the mouth is in the centre of the body; and the eyes are placed at the greatest possible distance from it, one at the extremity of each ray.

62. The highest of these four divisions is that denominated VERTEBRATA, or *Vertebrated Animals*; it receives its name from the structure characteristic of it,—the possession of a jointed back-bone,—which will be presently described. This is the group to which Man belongs; and all the animals it contains bear a greater or less resemblance to him in structure. We notice in regard to their external form, that they are all alike on the two sides of their body; every part having its fellow on the other side. This symmetry extends to the arrangement of those internal parts, which are connected with the functions of animal life; namely, the nervous system, the organs of sense, and the muscular apparatus. But it does not extend to the

organs of nutrition, which are unequally disposed on the two sides: thus, the heart and stomach are on the left side, the liver on the right, and the lungs much larger on the right side than on the left.

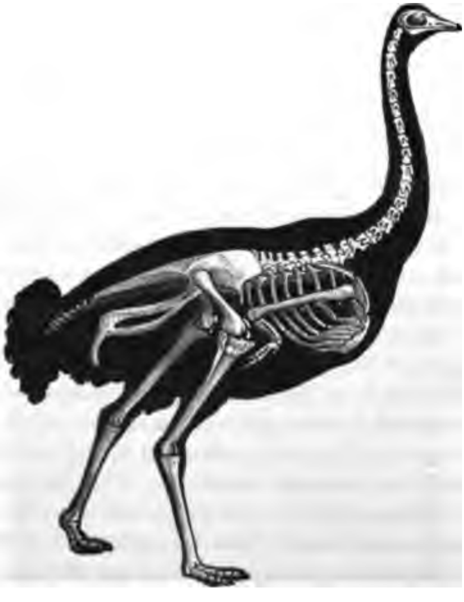

FIG. 4.—SKELETON OF THE OSTRICH.

63. In all Vertebrated animals, the skeleton is *internal*; and consists of *bones*, which are capable of growing, and of being reproduced after injury, like any other part of the living tissue; being copiously supplied with blood-vessels, which penetrate into their interior. These bones give support, and afford points of attachment, to the soft parts, in the limbs (where they exist) as well as in the trunk; but the former are not unfrequently wanting, as in Serpents; and we must look in the trunk, therefore, for that peculiar arrangement, which is characteristic of this division of the Animal Kingdom. The back-bone, as it is commonly termed, is found in all Vertebrated animals; though in a few among them (the lowest Fishes) it is very imperfect. It consists of several pieces jointed together, so as to possess great flexibility; whilst they are so firmly connected by ligaments, that they cannot easily be torn asunder or displaced. The number of these pieces varies considerably; in Man there are only 33; but in many Serpents there are several hundred. Each of them

is termed a *vertebra;* and the whole structure, composed of the united vertebræ, is termed the *vertebral column* (Fig. 5.)

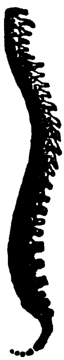

FIG. 5.—VERTEBRAL COLUMN.

64. The essential character of the vertebræ is, that each is perforated by an aperture, which, united to the corresponding apertures of those above and below it, forms a continuous canal; and in this canal, one of the most important parts of the nervous system,—the *spinal cord* (commonly but erroneously termed the spinal marrow [*])—is contained. The solid portion of the vertebra (Fig. 6, *a*), is termed its *body;* and the projections, *b* and *c*, are termed its *processes*, the former *spinous*, the latter *transverse*. The row of spinous processes forms the ridge which we feel passing down the back; it is seen on the right hand side of Fig. 5. To the transverse processes the ribs are attached. The vertebral column is expanded (as it were) at its upper extremity, to form the skull; in the large cavity which it contains, the brain is lodged; and its bones are so arranged, as to give protection to the organs of sense also. At the opposite extremity, we see it contracted into the tail; which is composed of a series of vertebræ resembling those of the back, but simpler in their form, and not possessing a cavity for the spinal cord. We commonly find that, in those animals in which the skull is very large, the tail is short; and that, where the tail is very long or powerful, the head is small. Thus in man, and in the apes, the head is large, and there is no external appearance of a tail; but there are some very imperfect vertebræ at the lower end of the spinal column, which constitute the rudiment of it. In the long-tailed monkeys, and in the kangaroo (whose tail is like a third hind-leg) the head is comparatively small. But this rule does not hold good universally.

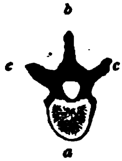

FIG. 6.—SINGLE VERTEBRA.

65. The nervous system of Vertebrated animals consists of a *brain* and *spinal cord*, which are lodged within the skull and

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[*] The *marrow* of bones in general, is an oily matter, which seems to contribute to their nourishment. The *spinal marrow* is a part of the nervous system.

vertebral column ; and of nervous trunks proceeding from these, which are distributed to all parts of the body. The brain and spinal cord are termed the *nervous centres ;* since it is in them that the power of this system resides; the trunks or cords being only conductors of its influence. The distinguishing feature of this system in Vertebrata is, that its several centres are thus united into one large mass, instead of forming a number of separate small masses or *ganglia,* as we shall find that they do in the lower classes of animals : and that it is enclosed in the bony casing, which has been described as peculiarly destined for its protection, instead of being enveloped with all the other organs, in a hard covering, as in the lobster ; or of being entirely destitute of protection, as in the slug. That it should receive this peculiar protection is quite necessary, in consequence of the much higher development which it attains, and the much greater importance which it possesses, in this division of the animal kingdom, than in any other.

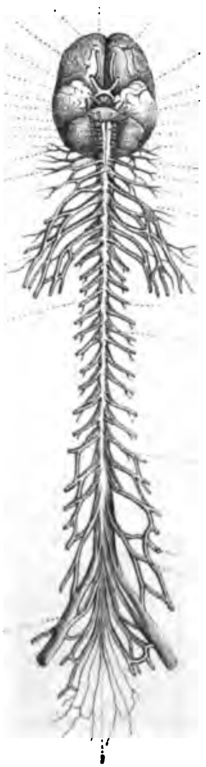


FIG. 7.—BRAIN AND SPINAL CORD OF MAN.

66. The general arrangement of the other organs in Vertebrated animals, is shown in the succeeding page (Fig. 8). At *m* is seen the mouth, forming the entrance to the digestive cavity, of which the termination is at the opposite extremity of the body ; *i*, *i*, is the intestinal canal, and *l*, the liver : these organs occupy the part of the body which is called the *abdomen* or belly. The mouth also opens, however, into the windpipe or trachea, *t*, which conducts air into the lungs, *p ;* these organs, with the heart, *h*, are contained in the portion of the trunk called the *thorax*, or chest. At *b* is seen the position of the brain ; and at *s* that of the spinal cord.

67. The foregoing characters apply, with greater or less modification as to details, to the classes of *Mammalia* (commonly

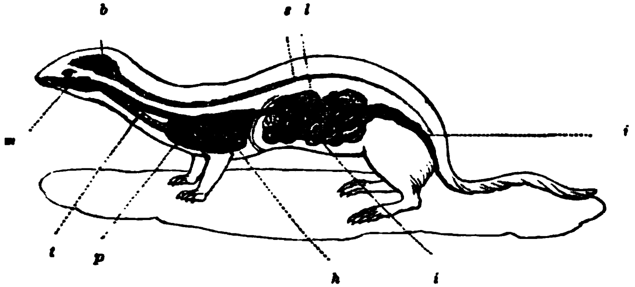


Fig. 8 —Diagram, showing the position of the principal Organs in Vertebrata.

termed Quadrupeds), *Birds*, *Reptiles*, and *Fishes ;* and these further agree in the following points, all of which, therefore, enter into our idea of a Vertebrated animal. The number of limbs or members never exceeds *four ;* and of these, two, or even all four, may be absent. In all the classes just named, four is the *general* number ; and the absence of two or more is the *exception.* Thus in Mammalia, we find all four present in every tribe save that of Whales, which want the hinder pair ; though the upper or anterior pair may take the form of arms, wings, legs, or fins, according to the element which the animal is formed to inhabit. In Birds we find the posterior pair invariably present, in the form of legs ; whilst the anterior pair, though almost always developed into wings, is absent in a few instances. In Reptiles we find considerable variety : all four members are present in the Turtle tribe, and in most Lizards, as well as in the Frog tribe ; but they are entirely absent in the whole tribe of Serpents ; and there are Lizards which have only one pair. And in Fishes, we usually find two pair, constituting the pectoral and ventral fins ; but one or both pairs are sometimes absent, as in the Eel, Lamprey, &c.

68. We have further to remark, in regard to the general characters of Vertebrated animals, that they have all *red* blood (§. 226) ; and that they possess a complex apparatus for circulating this through the body. Lastly, in all but the very lowest, all five kinds of sensation exist ;—namely, sight, hearing, smell,

taste, and touch. We find in this group more *intelligence* than in any other; that is to say, the animals composing it act more with a designed adaptation of means to ends; instead of being impelled by instinct to perform actions, of whose objects they are not aware. And we find, by observing and comparing the structure and actions of the different groups, that the intelligence gains upon the instinct, as we ascend from the lowest fishes towards man, in whom the intelligence is at its highest: whilst we observe a similar increase in the proportion, which the brain bears to the rest of the nervous system. Hence we conclude, that the brain is the organ of *intelligence*, or of the *reasoning faculties*.

69. All the animals which are destitute of a vertebral column, are called *Invertebrata;* and this division into the vertebrated and invertebrated groups, was formerly regarded as the first step in the classification of the animal kingdom. But it was pointed out by Cuvier, that in the invertebrated division are comprehended three groups, of which the members differ as much from one another, as they do from vertebrated animals; and that each of these ought, therefore, to rank with the first, as a primary division. This is evident to those, who are but slightly acquainted with the structure of the animals already named (§. 59) as characteristic specimens of these divisions; and it will become more apparent as we proceed.

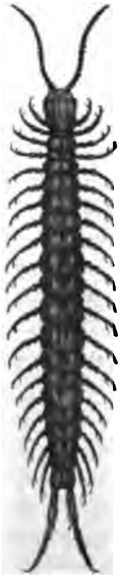


FIG. 9. CENTIPEDE.

70. In the second division, that of ARTICULATA, or *Articulated* (jointed) animals, we find a conformation very different from that which has been just described. The exterior of the body is still perfectly symmetrical, as in the vertebrata: and the interior is even more symmetrical; for the organs that represent the heart and lungs are equally disposed on the two sides of the central line of the body. But the skeleton, instead of being internal, is *external;* and is composed of a series of pieces jointed together, which form a casing that includes the whole

body. In general, these pieces are very similar to each other; so that the whole body appears like the repetition of a number of similar parts, as we see in the Centipede (Fig. 9). The limbs are usually very numerous, where they exist at all; and they have a jointed covering, like that of the body. But in the lower tribes of this group, such as Leeches and Worms, the limbs or members are but slightly developed, or are altogether absent; and in the highest, which approach most nearly to the Vertebrata in their general organisation, the number of members is much reduced, —although it is never less than six. The hard matter of which the external skeleton is composed, undergoes little or no change when it is once fully formed; and, in order to accommodate it to the increasing size of the animal, this covering is thrown off and renewed at intervals.

71. The nervous system consists of a series of small masses or *ganglia*, which are arranged in a cord or chain along the central line of the body. There is usually a large ganglion in the head, bearing a resemblance (in its peculiar connection with the eyes) to a certain part of the brain of Vertebrata; and there is commonly one for each segment or division of the body, from which the nerves pass to supply its muscles, as they do from the spinal cord of Vertebrata. The cord which connects these ganglia is double; and the ganglia themselves are composed of two halves which have little connection with each other. The chain thus formed, passes along the under side of the trunk of the animal (as seen at *g*, Fig. 11), not on what seems its back; and it is by the presence of this double chain of ganglia that an Articulated animal may be distinguished, even when, in its general structure, it should seem to belong to the group of Mollusca (see §. 113).

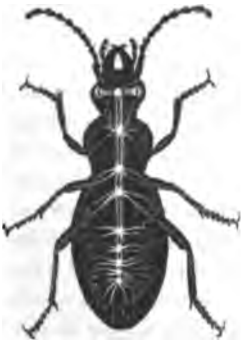


FIG. 10.—NERVOUS SYSTEM OF AN INSECT.

72. The general arrangement of the organs in the Articulata

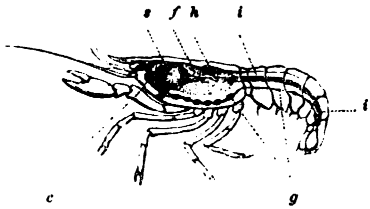


FIG. 11.—DIAGRAM SHOWING THE POSITION OF THE PRINCIPAL ORGANS IN THE ARTICULATA.

is shown in the accompanying figure of a cray-fish. The mouth, situated on a projecting head, opens into *s*, the stomach, from which passes backwards the intestinal tube, *i*, *i*, to terminate at the opposite extremity of the body. The upper part of the tube is surrounded by the liver, *f*, which is here very large. In the head are seen the ganglia, *c*; and along the under side of the body is seen the chain of ganglia, *g*. The organs which answer to the lungs of Vertebrata are not connected with the mouth; and are not usually restricted to one part of the body, but are diffused either on its outside, or through its substance. The organs of sense, in this group, are less numerous than in Vertebrata, and are inferior in perfection. The blood is nearly colourless; and the heart, *h*, by which it is impelled through the body, is much less energetic. Yet we find that the muscular power is very great; for the animals of this group, taken as a whole, can move faster in proportion to their size, and possess greater strength, than those of any other. We observe, too, that with little or no intelligence, they are prompted to the most remarkable actions by *instinct* alone. They seem to act like machines, doing as they are prompted, without choice, or knowledge of the end to be gained; and consequently the different individuals of the same species have not that difference of capacity and of disposition, which we see in animals whose endowments are higher.

73. The general character of the animals composing the group or division MOLLUSCA, is, in many respects, the very opposite of that which belongs to the articulated animals. The body is soft (whence the name of the group is derived), neither possessing an internal skeleton, nor any proper external skeleton. In some of the most characteristic specimens of the group, such as the slug, there is no hard frame-work or skeleton; and thus the body is alike destitute of support and protection. In many

molluscs, however, the body has the power of forming a shelly covering, which serves for its protection; but this does not give any assistance in its movements, by affording fixed points for the attachment of the muscles; in fact, when the animal puts itself in motion, it is obliged to make its locomotive organs project beyond the shell (Fig. 12). We must not regard the shell as an essential part of the Molluscous animal; because there are many tribes entirely destitute of it; and also because some of the Articulata have the power of forming a shell, which bears a close resemblance to that produced by the animals of this group. Not unfrequently we see that, of two animals whose general structure is almost exactly the same—as that of the snail and slug, one possesses a shell, into which it can withdraw its whole body for the sake of protection, whilst the other has none; and that several intermediate forms exist, in which the shell bears a larger or smaller proportion to the body, sometimes being able to contain nearly the whole of it, and sometimes being a mere rudiment, as in the Testacella (Fig. 13).

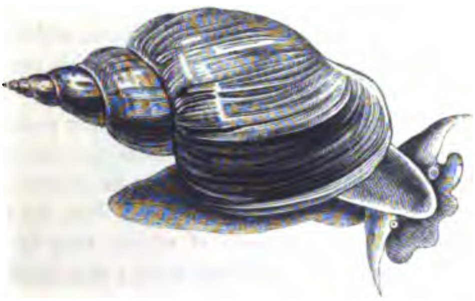


FIG. 12.—LYMNÆUS STAGNALIS.

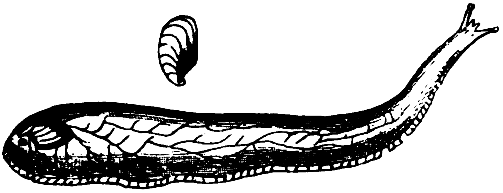


FIG. 13.—TESTACELLA.

74. The external form of the body of the Mollusca is subject to great variation; and generally has a good deal to do with the degree in which the organs of sense and the instruments of motion are developed in the particular animal. For *these* are

almost always symmetrical, being arranged with equality on the two sides of a middle line; whilst the rest of the body, containing the organs of nutrition, is often unequal on the two sides. This is the case, for instance, with the *Lymnæus* (Fig. 12), which is represented in the act of crawling on its large fleshy disc or foot, with its head, bearing its eyes and feelers, projected forwards.—But in the lower Mollusca, which have little or no power of moving from place to place, this regularity of arrangement is altogether lost.

75. Few of the Mollusca have any powers of active movement; in fact, the term *sluggishness*, derived from a characteristic member of the group, very well expresses their general habit. They usually crawl upon a fleshy disc, by the successive contractions and relaxations of which, they advance slowly along the surface over which they move; this kind of action is easily studied, by causing a snail or slug to crawl upon a piece of glass, and by looking through this at the under side of its foot. Hence, there is a great contrast between the inertness of the Mollusca, and the high activity of the Articulata. This contrast shows itself in the structure of their bodies; for whilst the chief part of the interior of an insect is made up of the muscles which move its legs and wings, the apparatus of nutrition being small,—the chief part of the bulk of a slug or snail is given by its very complex apparatus for nutrition, there being no other muscles (except some small ones connected with the mouth and head) than the fleshy disc already mentioned.

76. The accompanying figure of the interior of a Snail will show the very large size of the digestive apparatus, and of the other organs of nutrition. The muscular disc or foot is seen at *f*; and at the extremity of this are seen the tentacula or feelers, *t* (commonly termed horns), half contracted. The mouth, situated in the neighbourhood of these, opens into a tube that leads to the stomach, of which a portion is seen at *s*; and from this cavity proceeds the intestine, *i*, which passes forwards again as seen at *r*, to terminate at *a*. This termination of the intestine near the mouth is very frequent in Mollusca; and is obviously necessary, when the body is enclosed in a shell that has only one outlet. The liver, *l*,

is a very large mass, surrounding the stomach and intestine. The heart is seen at *h;* and from it is seen to proceed a large vessel, *a p*, that ramifies upon the walls of a cavity, *p*, which answers to the lungs of higher animals; this cavity is separated from the other organs by a kind of diaphragm or partition, *d*, which is here turned to one side. At *ar* is shown the artery which proceeds from the heart, to convey blood to the general system. At *o* is seen the ovarium, in which the eggs are formed; this ocupies the highest part of the shell; but it has a canal which terminates near that of the intestine. And lastly, at *v* is pointed out a gland that secretes the viscous or slimy fluid, with which the body of the animal is covered; and this is carried out by the canal *cv*.

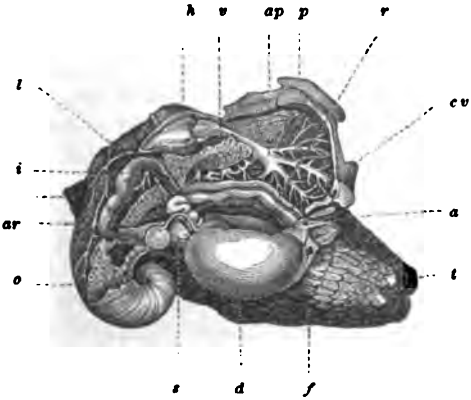


FIG. 14.—ANATOMY OF THE SNAIL.

77. Thus it is seen that,—whilst the body of an Articulated animal may be compared to that of a man, in whom the apparatus of nutrition (contained in the chest and abdomen) is of the smallest possible size, but whose limbs are strong, and his movements agile,—the body of a Mollusc resembles that of a man 'whose god is his belly,' his digestive apparatus becoming enormously developed, whilst his limbs are feeble, and his movements heavy. Such varieties, in a greater or less degree, are continually presenting themselves to our notice.

78. The nervous system of the Mollusca generally consists of a single ganglion or pair of ganglia, which are placed in the head, or (when that is deficient) in the neighbourhood of the mouth; and of two or more separate ganglia, which are found in different

parts of the body, and are connected with the preceding by nervous cords. The former correspond to those contained in the head of insects; but of the latter, one only is connected with the foot or organ of motion, the remainder having for their function to regulate the action of the gills, and to perform other movements connected with the operations of nutrition. In Fig. 15 is represented one of the simpler forms of this nervous system,—that of the *Pecten* or scallop-shell; A A are the ganglia near the mouth, from which the organs of sense are supplied; B is the ganglia connected with the gills; and C is that from which power is given to the foot. The two first lie wide apart, but are connected by an arched band that passes over the gullet, *e*. The organs of sense among the Mollusca are but little more developed than those of motion. They serve to direct the animal to its food, and to warn it of danger; but there seems an absence, in all but the highest species, of that ready and acute sensibility which is so remarkable in the preceding groups; and the variety of impressions which they can receive appears to be but small. In no instance has a special organ of smell been certainly discovered; the organ of hearing is always imperfect, and frequently absent altogether; and the eyes are very often wanting; so that touch and taste (which is but a refined kind of touch) are the only senses left. —The blood of the Mollusca is white, as it is in the Articulata; but the apparatus by which it is circulated through the body is much more powerful and complete.

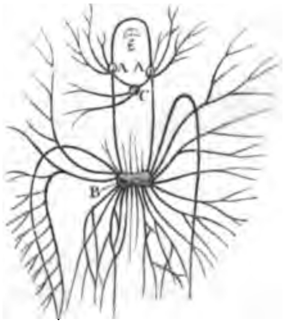


FIG. 15.—NERVOUS SYSTEM OF PECTEN.

79. The fourth and last subdivision, that of **RADIATA**, includes those animals which have the parts of the body arranged in a circular manner around a common centre, so as to present a *radiated* or *rayed* aspect. This arrangement is well seen in the common Star-fish, which has five such rays, all having a pre-

cisely similar structure, and thus *repeating* each other in every respect. The mouth of this animal is in the centre; and it opens into a stomach, which occupies the central disc, and sends prolongations into the rays. The nervous system is, in like manner, composed of a repetition of similar parts. A plan of it is seen in Fig. 17; where *a* shows the position of the mouth, which is surrounded by a ring or nervous cord, having five ganglia, corresponding to the five arms. From each of these ganglia proceeds a branch along its arm, terminating in a little organ at its extremity, which is believed to be an imperfectly developed eye. No other organs of special sense can be detected in any of these animals; and it is only in a few that even these imperfect eyes can be discovered. All parts of their structure appear to be reduced to their greatest

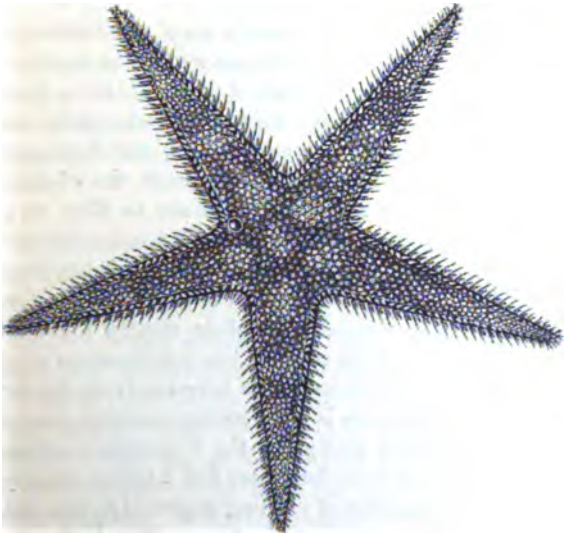


FIG. 16.—STAR FISH.

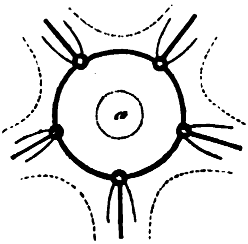


FIG. 17.—NERVOUS SYSTEM OF STAR-FISH.

simplicity of form; and at last we come down to that which has been already noticed (§. 13, 14) as the simplest type of a decidedly animal structure,—a stomach or digesting sac, with an orifice that serves as the mouth, and a set of arms arranged in a circular manner, around this orifice, as we find in the Hydra.

80. It is only among the highest of the Radiata, that there exists a circulation of nutritive fluid in distinct vessels: in most of the animals which this group includes, the fluid and solid parts are in contact with each other through the whole body; and their tissues bear a close resemblance to those of plants. The circular arrangement of their organs is a more obvious point of resemblance to the Vegetable kingdom; and this has frequently caused mistakes to be made in regard to the sea-anemonies, and other large polypes, which, when their mouths are open and their arms spread out, look so much like the blossoms of some of the composite tribe of plants, as to have received the name of *animal flowers*. But there is yet a stronger analogy between the lowest of the Radiated group and the Vegetable kingdom; for among the former, as in the latter, we find a union of many individuals, which are capable of existing separately, into one compound structure, having a plant-like form. This is the nature of the stem of coral (Fig. 76); which is, in fact, the skeleton of one of these compound systems, consisting of a number of polypes united by a jelly-like flesh; just as the woody stem of a tree is the skeleton that supports a vast number of buds, each of which is capable of living by itself (See VEGET. PHYS. §. 305). In consequence of this remarkable union, it is often very difficult to say, whether a particular mass is to be regarded as a single animal, or as a collection of many. To the tree-like fabrics thus produced, the name of *zoophytes* (animal plants) is commonly given; and ordinary observers often find it difficult to get rid of the idea of their vegetable origin. The animals that formed them are, of course, fixed to one spot during all but the earliest periods of life; and the amount of movement which they perform, for the purpose of obtaining and securing their food, is very little greater than that which has been described in the Sensitive plant, and Venus's fly-trap (See VEGET. PHYS. §. 421).

81. In regard to the situation of the skeleton of the Radiata, there is very great variety; as there is in respect to the arrangement of the organs. In the *star-fish* and *sea-urchin*, the body is enclosed in a hard casing, furnished with prickles or spines. In the *jelly-fish* and *sea-anemone*, it is altogether destitute of any hard support or protection. And in the *coral-forming* tribe, a massive internal skeleton is generally produced; though in some few instances the stony matter forms a tube, which envelops the soft parts.

Division of the Animal Kingdom into Classes.

82. The various animals which are united into each of the four preceding groups, or primary divisions of the Animal Kingdom, whilst agreeing among themselves in the general characters that have been enumerated, differ from each other in important points; and it hence becomes necessary to subdivide these again, according to the manner in which their functions are respectively performed. Thus, among Vertebrated animals, there are some which produce their young alive, and which nourish them afterwards by suckling; while the greater part rear them from an egg which contains a store of nutritive matter, and do not afford them any further nourishment from their own bodies. Again, some breathe air; whilst others live constantly in water, and have no direct communication with the atmosphere. Some, moreover, have the power of keeping up a high temperature, so that their bodies always feel warm to the touch; whilst the temperature of others varies with that of the atmosphere, so that their bodies give a feeling of coldness. The former are termed *warm-blooded;* the latter *cold-blooded.* There is a like difference in their mode of life; some of them being destined to live on the surface of the earth, whilst others are chiefly inhabitants of the air, and others again are the tenants of the ocean. These differences are so well marked, that they afford a ready means of subdividing the Vertebrated group into four classes, MAMMALIA, BIRDS, REPTILES, and FISHES. The chief peculiarities of these will now be explained.

83. The MAMMALIA are distinguished by the first of the

characters mentioned in the last paragraph; being the only animals that produce their young alive, and which nourish them afterwards by suckling. They are for the most part *quadruped* (that is, four-footed), and destined to live upon the surface of the earth; but *man*, and the *apes* that approach nearest to him, are *biped*, having the power of walking on two limbs, and of using the others for different purposes; whilst the *bat* tribe have the two arms converted into wings, which enable them to fly through the air like birds (for which the older naturalists mistook them); and the *whale* tribe are adapted in their general form to lead the life of fishes (among which they are still commonly ranked by persons ignorant of natural history), having the hinder part of the body prolonged and spread out into a broad flattened tail, whilst the anterior limbs are converted into short fin-like paddles, and the posterior are altogether wanting. Notwithstanding these marked differences in external form, there is a great correspondence as to internal structure; for bats and whales, as well as ordinary quadrupeds, produce their young alive, and suckle them afterwards; they are also warm-blooded, breathing air, and having an active circulation. Their bodies are, for the most part, more or less completely covered with hair, which serves to keep in their warmth; and this is seldom absent, except in animals which inhabit warm climates, and which do not require this provision. In the whales, the same end is answered by the thick layer of oil in the substance of the skin, constituting the blubber; and man is left to form a protective covering for his body, by the exercise of his own ingenuity.

85. The general conformation of the skeleton of Mammalia, is shown in the subjoined figure, which represents that of a Camel, —the black ground showing the outline of its form, when clothed with flesh. The head is supported upon a neck, which, whether long or short, always contains seven vertebræ (*v c*, the cervical vertebræ); the number of the vertebræ of the back (*v d*, the dorsal vertebræ), and that of the vertebræ of the loins (*v l*, the lumbar vertebræ), varies considerably in different animals. In most quadrupeds the spinous processes (§. 64) of the vertebræ of the back form a high ridge, for the purpose of giving attachment

to the muscles and ligaments by which the heavy head and neck are supported. Several of the vertebræ at the hinder end of the spinal column are united into a single bone (*v s*, the sacrum), by which they are connected with the framework that supports the legs. Behind this, they are again separate in the tail (*v q*, the caudal vertebræ). To the transverse processes of the vertebræ are attached the ribs, *c*, by which the upper part of the cavity of the trunk is protected; the ribs are prolonged by cartilages that meet under the body in the breast-bone, which in most of the mammalia is flat. Upon the ribs lies on each side the blade-bone, or scapula, *o*; and this forms part of the shoulder-joint, and gives attachment to some of the muscles by which the fore-leg is moved. Each anterior limb consists, first, of the humerus, or arm-bone, *h*, which lies between the shoulder and the elbow; then of two bones giving support to the fore-arm, which are commonly united, however, in herbivorous quadrupeds, into a single one, *cu*; next, of the bones of the wrist, *ca*, which are also

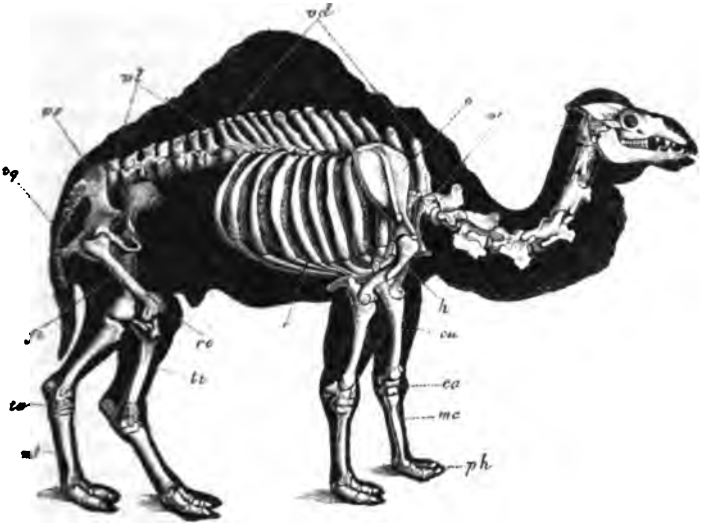


FIG. 18.—SKELETON OF THE CAMEL.

few in number, in animals that do not possess separate fingers; and lastly of the bones of the hand, *mc*, and those of the toes, *ph*. The hind-leg, united to the vertebral column by a framework called the *pelvis*, contains a corresponding series of bones; the femur or thigh-bone, *fe*; the knee-pan, *ro*, a little bone which lies upon the knee-joint; the two bones of the leg, here united into one, *ti*; the bones of the ancle, *ta*; those of the foot and toes, *mt*.

86. The general arrangement of the internal organs will be seen from the accompanying figure of the body of a Monkey, laid open in such a manner as to exhibit the chief of them. The cavity of the trunk is completely divided, by the muscular partition termed the *diaphragm*, into two portions,—the *thorax*, containing the heart and lungs,—and the *abdomen* containing the digestive apparatus. It is by the alternate contraction and relaxation of this muscle, that the act of breathing is performed in Mammalia, as will be explained hereafter (§. 381).

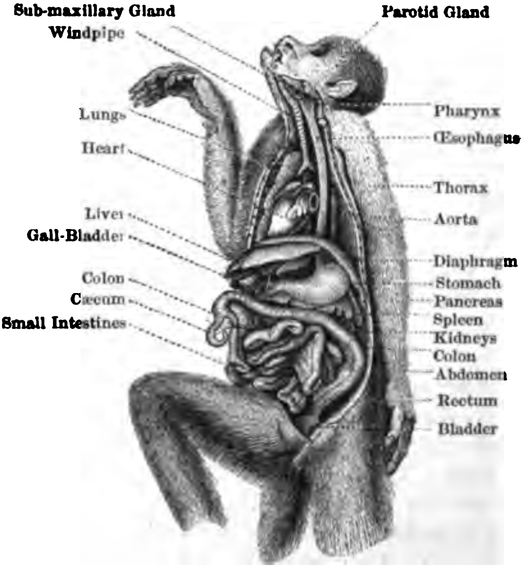


FIG. 19.—INTERIOR OF A MONKEY.

87. In BIRDS, there is a much closer conformity to one general plan than we find in Mammalia. The covering of feathers, by which we ordinarily distinguish the members of this class, prevails universally; and there is no wide departure from the form, which we are accustomed to regard as characteristic of this interesting group. This class belongs to the *oviparous* division of the Vertebrata; since the young are reared from eggs. But it is distinguished from Reptiles, which are also oviparous and air-breathing, by being warm-blooded; and by having a very energetic, instead of a very slow circulation. The covering of feathers is given, not only to keep in the heat of the body, which is even greater than that of Mammalia, but also to afford the required surface for the wings, on which the bird is supported and propelled through the air. The feathered portion of the wings is stretched out upon the bones which answer to those of our arm, and is moved by its muscles. The wings are very small, or entirely absent, in the Ostrich and a few other birds, which present the nearest approach to the Mammalia in their internal structure; and these cannot rise from the ground, but run swiftly along it, by means of their powerful legs. In the Penguin, also, the wings are small; and they are used as fins, by the assistance of which the bird, which can neither walk nor fly with rapidity, can swim very quickly through the water.

88. The general form of the skeleton of Birds is shown in Fig. 20, which represents that of the Vulture. The head is supported upon a very flexible neck, of which the vertebræ are often very numerous (*v c*). The vertebræ of the back and loins, however, are usually few in number, and are connected together very firmly, so as to form a nearly inflexible column; and this again is closely united to the sacrum, *v s*. The vertebræ of the tail, *v q*, are also small in number, and possess little motion. The ribs are very strongly connected to each other and to the vertebræ, and are united to the breast-bone, *s t*, by bony instead of cartilaginous prolongations. Thus the whole bony apparatus of the trunk is very strongly knit together; and the purpose of this is evidently to give as firm an attachment as possible to the muscles which move the wings. The greatest power which these

organs require, is in the downward direction; in order that, by their stroke, they may raise the bird in the air, or keep it from falling. Accordingly we find that the great mass of flesh or muscle that puts them in action, lies on the breast-bone, the centre of which, *st*, is raised into a high keel or ridge for its attachment. On the other hand, the muscles that raise the limb, and draw it backwards, which are attached to the blade-bone of Mammalia, and are usually strong in them, are comparatively weak in birds, whose scapula (forming part of the *side-bone*) is very narrow. Moreover, in order to keep the wings properly apart, there is a very strong clavicle or collar-bone, *c l*, in birds; and this, though it exists in Man, and in Mammalia that use their fore-arm for other purposes than support and motion, is deficient in the greater part of those that employ it only as a leg.

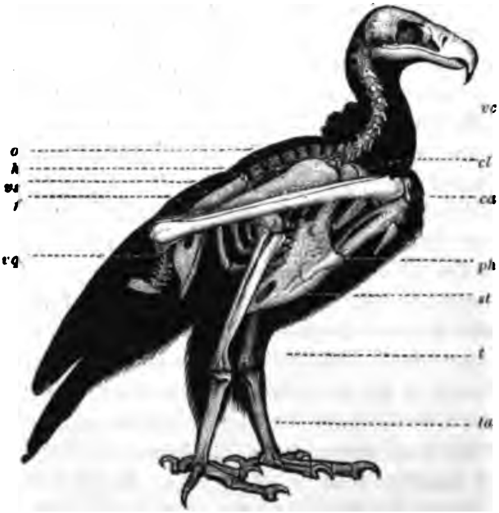


FIG. 20.—SKELETON OF THE VULTURE.

89. The bones with which the wings are connected are better seen in Fig. 21; where *o* represents the narrow blade-bone; *f*, the clavicle or collar-bone; *c*, a bone that seems like a second collar-bone, being an extension of what is a mere

process or projection on the scapula of Mammalia; *s*, the sternum or breast-bone; *e*, its lower border; *b*, its keel or ridge projecting forwards; and *s*, the attachment of the ribs. The amount of the projection of the keel of the sternum corresponds with the size of the muscles that are to be attached to it; and upon this depends the power of flight which the bird possesses. In the Ostrich, and other birds whose wings are not developed, the sternum is flat as in Mammalia.—Returning to Fig. 20, we notice further the *humerus* or arm-bone, *h*, constituting the first bone of the pinion; the two bones of the *fore-arm*, *o*; the bones of the wrist *c a*, which are here scarcely developed; and the bones of the fingers, *ph*, each joint of which shows indications of being made up of two or three separate bones united together. In no Bird are these bones ever separated into distinct fingers; since they are never applied to any other purpose than that of supporting the wing-feathers. In the hinder extremity of the bird we find a thigh-bone, *f*, (principally concealed in the figure by the bones of the wing), the two bones of the leg, *t*, which are commonly in part united; the shank or ancle bones, *ta*, and the four separate toes, by the spread of which the body is firmly supported, though it rests only on two feet.

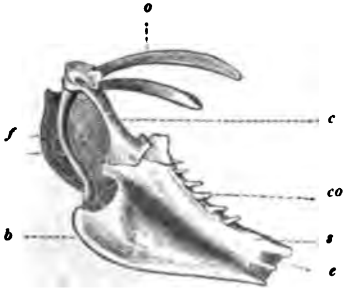


FIG. 21.—BONES OF THE SHOULDER AND BREAST OF BIRDS.

90. The arrangement of the organs contained in the cavity of the trunk of Birds differs from that which has been described in the Mammalia, chiefly in this,—that there is usually no diaphragm to separate the chest from the abdomen, and that although the lungs themselves are confined to the upper part of this cavity, they are connected with a series of air-sacs, which are distributed through the whole of it. In the accompanying figure, which represents the internal organs of the Ostrich, the heart is seen at *a*, the stomach at *b*, and the intestinal tube at *c*. The windpipe, *d*,

opens into the lungs, *e*, which are themselves small, and are attached to the ribs, instead of lying freely in the cavity of the chest; but the space they would otherwise have occupied is filled up by the large air-cells, *f*, *f*, which communicate freely with the lungs and with each other, and which even occupy a large part of the cavity of the abdomen, as seen in the figure. The use of these air-cells in the respiration of Birds, will be explained hereafter (§. 356).

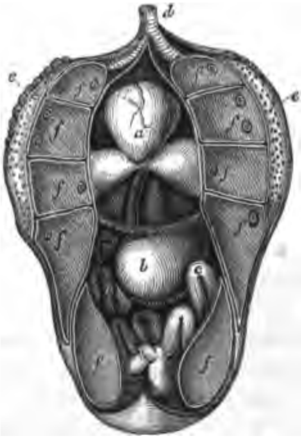


FIG. 22. LUNGS OF THE OSTRICH. *a* the heart, *b* the stomach, *c c* the intestines, *d* the trachea, *e* the lungs, *f f f* air-cells, in which are also seen the tubes by which these air-cells communicate with the lungs.

91. In the class of **REPTILES** we find a variety of form so remarkable, that, if we were influenced by this alone, we should scarcely regard the animals it contains as belonging to the same group; yet the structure of the internal organs, on which classification is founded, is essentially the same in all. Four obviously different tribes, *turtles*, *lizards*, *serpents*, and *frogs*, are brought together by the following characters. They are all *oviparous* (Chap. xv.), in this respect agreeing with Birds and Fishes; but they are cold-blooded, and have not a complete apparatus for the double circulation of the blood, in which respect they differ from Birds; and they breathe air by means of lungs, instead of breathing water by gills, in which respect they differ from Fishes. But by the lowest group, that of frogs and their allies, this class is united to that of fishes in a most remarkable manner; for these animals in their young state breathe by gills, and lead the life of a fish; and some of them retain their gills during the whole of life, even after the lungs are developed (§. 97). The first three of the tribes just mentioned, undergo no such change: and they further agree in this, that they breathe air during the whole of their lives, coming forth from the egg in the same condition as

that in which they are subsequently to live, and also in having their bodies covered with horny scales or plates, whilst the skin of the Frog tribe is soft and unprotected. These differences are considered by some naturalists as sufficient to require the separation of the Frog tribe into a distinct class, to which the name of *Amphibia* (which properly means animals that can live either in air or water) is given.

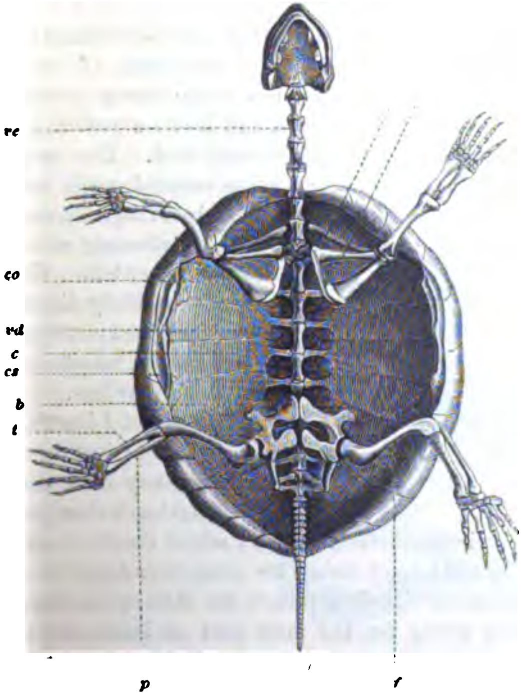


FIG. 23.—SKELETON OF THE TURTLE.

92. The *Turtle* tribe is peculiarly distinguished by the inclosure of the body in a bony covering; of which the upper arched portion (termed the *carapace*) is formed by an expansion of the ribs, which grow together, as it were, at their edges, so as to form a continuous plate; whilst the lower flat plate (termed the

plastron) which is often incomplete, is formed by a similar expansion of the sternum or breast-bone, which is here spread out sideways, instead of being raised into a projecting keel, as in Birds. The accompanying figure will show the general construction of the skeleton of this tribe, the sternum being removed. As in the preceding figures, *vc* are the cervical vertebræ, and *vd* the dorsal vertebræ; *c* are the ribs extended in width, so as to unite at their edges; *cs* are the bony pieces which connect these ribs with the sternum; *o*, is the scapula or blade-bone, here very narrow, as in birds; *cl*, the clavicle; *co*, the additional clavicle, as in birds; *b*, the bones of the pelvis which support the lower limbs; *f*, the thigh-bones; *p* and *t*, the bones of the leg. Although the bones of the toes are separate, they are enclosed in a single horny casing; this is flattened in the aquatic turtles, and forms a paddle; whilst in the land tortoises it forms a stumpy foot. The carapace and plastron are covered with large horny plates, variously arranged in the different species, and constituting what is commonly called *tortoise-shell*. These plates are often very beautifully disposed, forming a kind of tesselated pavement; as in the common Tortoise, which is often preserved alive in our gardens.

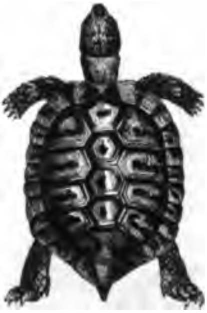


FIG. 24.—TORTOISE.

93. In the tribe of *Lizards*, the body has no such covering; but these animals, having more activity than the tortoises (which are proverbially slow) are enabled to make their escape from danger, whilst the latter are obliged to trust to their bony casing for protection from it. In their general form, the lizards approach the Mammalia, being all four-footed, and living for the most part on land; but they differ from them in the very important particulars already mentioned, as well as in several others of less consequence. In general, their bodies are covered with scales, which lap over one another like the tiles of a roof; but in the Crocodile tribe, many parts of the surface are covered with large knotted horny plates, that

meet at their edges, like the scales of tortoise-shell, and afford an almost impenetrable covering. Although some of the Lizard tribe spend a large part of their time in water, yet they all breathe air; but, as their respiration is very inactive, they can spend a considerable time beneath the surface, without being obliged to come up to breathe. There are some lizards in which the feet are extremely small, and the body much prolonged, as shown in the *Chalcis* (Fig. 26); and by these we pass to the next group.

Fig. 25.—Crocodile.

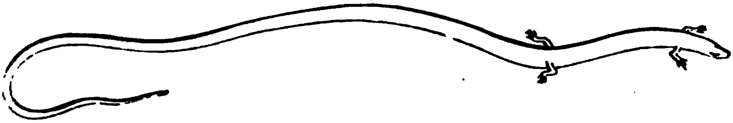


Fig. 26.—Chalcis.

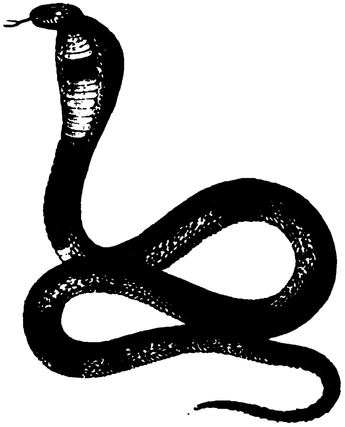


Fig. 27.—Naia Aspic.

94. The tribe of *Serpents* may be regarded as lizards without feet; their spinal column is immensely prolonged; and their ribs are also very numerous; and they are able to crawl upon the points of these, using them almost as the centipedes do their legs (§. 112). But in general, the movement of their bodies is accomplished by their being drawn up into folds, and then straightened so as to

project the head. The prolonged form of the body in Serpents, occasions a curious variation in the arrangement of the principal organs, which is shown in the accompanying figure. The œsophagus or gullet, *œ*, which leads from the mouth to the stomach, is a long and very wide canal, being even larger than the stomach at its commencement; a portion of it is removed at *œ'*, in order to show the heart, &c., which would otherwise be

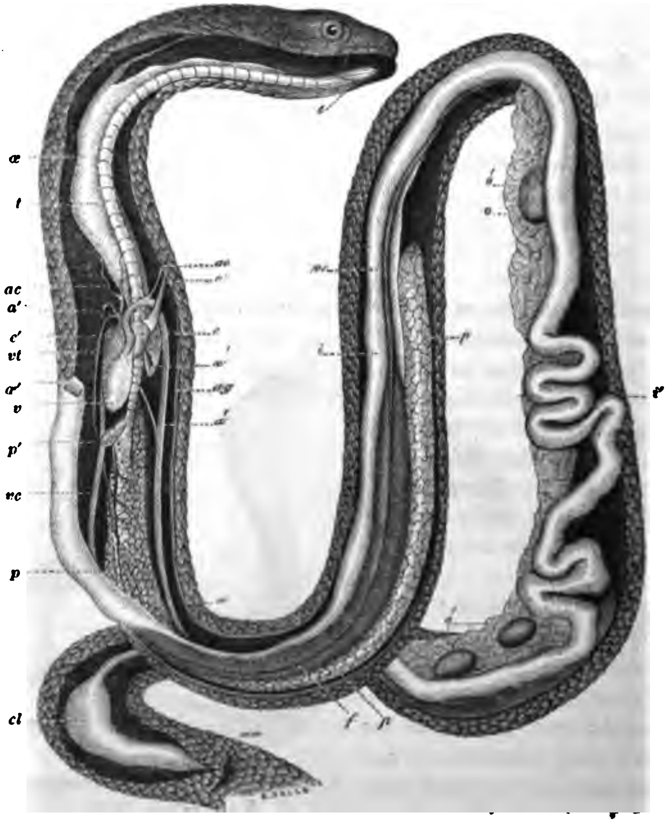


FIG. 28.—ANATOMY OF A COLUBER.

concealed by it. The stomach, *i*, is long and narrow; and the intestinal tube, *i′*, after making a few turns or convolutions, passes backwards in a straight line, to terminate in the cloaca, *cl*, which opens externally by the orifice *a n*. The liver, *f*, is also much lengthened. From the mouth also proceeds the long windpipe, *t t*, which conveys air to the lungs, or rather to the single lung; for the lung on the left side, *p′*, is scarcely at all developed, whilst that on the right, *p*, extends along a great part of the body. At *o* is seen the ovarium, in which the eggs, *o′o′*, are produced; and this also is very much lengthened, extending from the cloaca a good way up the body, so as nearly to meet the lung. The other references are to the parts of the heart, and the principal vessels; the structure and arrangement of which will be explained hereafter (§. 284). At *vt* is seen the single ventricle of the heart; *c* is the right auricle, and *c′* the left auricle; *ad* and *ag* the two arches of the aorta or great artery, from which proceed *ae*, *ac*, the carotid arteries to supply the head, and which unite to form *a′* the aorta of the trunk; *v*, the vena cava or great vein that returns the blood from the head and front of the body; and *vc*, the vein that brings it from the trunk.

95. The animals of the *Frog* tribe are readily distinguished from all the preceding, by their soft naked skins; even when the form of the body, as in the common salamander or water-newt, resembles that of the lizards. They are also remarkable for the metamorphosis which they undergo in the early part of their lives; for they come forth from the egg in a condition which is, in all essential particulars, that of a fish, and undergo a gradual series of changes, by which their form and structure become analogous to those of the true reptiles. This change is most complete in the frogs and toads; the early form of which is known as the *tadpole*. The principal stages of this change are represented in the accompanying figures; in which, however, the relative sizes are not preserved, the tadpoles being much larger in proportion (for the sake of displaying their form and the gradual development of their legs) than the adult frog.

Soon after the young tadpole has come forth from the egg, it presents the form which is shown in Fig. 29: its head and trunk are large, and the latter is prolonged into a flattened tail, by which the little animal swims freely through the water. There is not the least appearance of limbs or members. The gills are long fringes, hanging loosely in the water on either side of the head; and by these the tadpole breathes, as do the aquatic Mollusca.

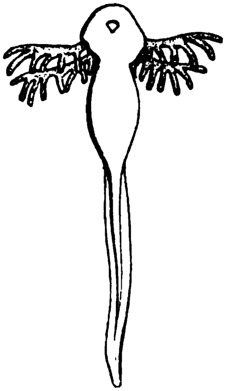


Fig. 29.

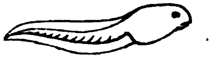


Fig. 30.

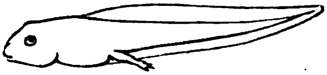


Fig. 31.

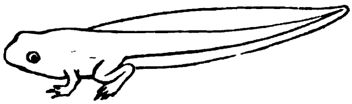


Fig. 32.

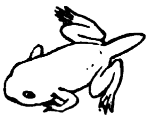


Fig. 33.

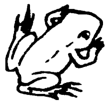


Fig. 34.

96. At a later period, however, these gills, which are merely temporary, disappear; and the breathing is carried on by another set, which are situated behind the head, and are covered in by a fold of skin; the water gains access to these by passing through the mouth, exactly as in Fishes. The form is then that which is represented in Fig. 30. In a short time afterwards, the animal still breathing by its gills, the hind-legs begin to sprout forth as it were, at the base of the tail; this stage is shown in Fig. 31. At a still later period, the fore-legs begin to be

developed, as seen in Fig. 32; and from that time they are nourished at the expense of the tail, which gradually disappears (Fig. 33.) During this period, other important changes are taking place in the interior of the body; the chief of which is the development of the lungs, and the gradual disuse of the gills, so that the animal becomes fitted to live on land and breathe air, and is no longer capable of remaining long under water, without coming to the surface to respire. The perfect form of the Frog is shown in Fig. 34.

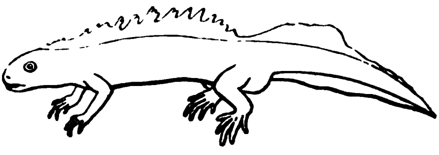


FIG. 35.—WATER-NEWT.

97. It has been said that the Frog itself undergoes a more complete metamorphosis than others of the group. Thus in the *Water-Newt* (Fig. 35), the tail is retained during the whole of life, and the animal continues to be an inhabitant of the water, though breathing air alone. There are some very curious animals, however, in which the change is stopped, as it were, at a much earlier period, so that the gills also are retained; and in these, the lungs are sufficiently developed to enable the animals to breathe air, so that they can live either on land or in water, and are thus truly *amphibious*. In Fig. 36 is represented an animal of this kind, the *Axolotl*, which inhabits some of the lakes of Mexico. And in Fig. 37 is shown

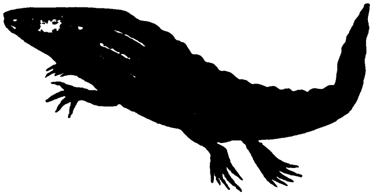


FIG. 36.—AXOLOTL.

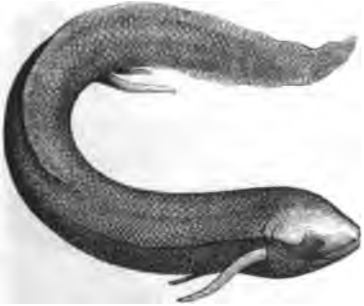


FIG. 37.—LEPIDOSIREN.

the form of a still more remarkable animal, the *Lepidosiren*, recently brought from the rivers of Africa, the metamorphosis of which appears to be checked at a still earlier period, so that it is very difficult to decide whether it should be regarded as a fish or a reptile, so complete is the mixture of characters which it presents.

98. The class of FISHES is distinguished from all other Vertebrata, by the adaptation of the animals composing it, to breathe by means of water in their adult state, so as to be capable of living in that element only. Like Reptiles, they are oviparous and cold-blooded; and in these characters they differ completely from the whales and other Mammalia, which are, like them, inhabitants of the great deep, but which are warm-blooded, viviparous, and air-breathing animals. There is a simple external character by which the members of the two classes may be at once distinguished. The animals of the whale tribe are, like fishes, chiefly propelled through the water by means of a flattened tail; but in the former the tail is flattened *horizontally*, so that its downward stroke may serve to bring the animal to the surface to breathe; whilst in the latter it is flattened vertically, that its strokes from side to side may simply propel the fish through the water. This flattening or compression of the body is seen more or less in almost all fishes; and it is intimately connected with the nature of their motion through the element they inhabit, as it serves the double purpose of dimi-

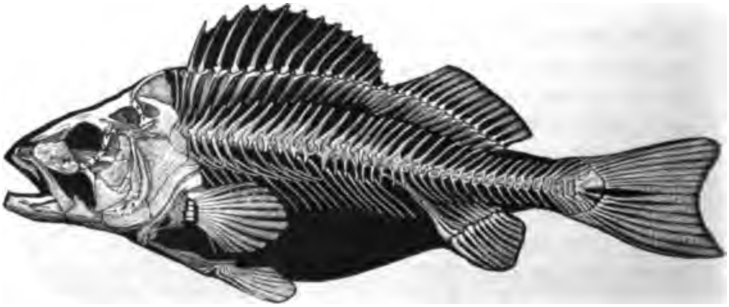


FIG. 38.—SKELETON OF THE PERCH.

nishing the resistance which it offers to their progress, and of increasing the extent of the oar-like surface, by the stroke of which the body is propelled forwards (Chap. XII).

99. The preceding figure of the skeleton of the Perch shows the bony apparatus, by which this extended surface is supported. The spinous processes of the vertebræ, which project upwards from the vertebral column, are long, and are connected with another set of bones, which continue them, as it were, into the finny expansion that rises from the back, of which they constitute the framework. There is a corresponding series of bones below; but they leave a part of the trunk free, to contain the viscera. They form another fin behind, however; and they spread out at the tail to support its large expanded surface. It is, therefore, by bending its spinal column, that the side stroke of the tail and of the hinder part of the body, is made, for the propulsion of the fish through the water; and thus, in this lowest group of the vertebrated series, the act of motion is performed by the vertebral column itself, instead of being committed to the limbs as in Birds and Mammalia. But these limbs or members are not altogether wanting in fishes; for there are usually one or two *pairs* of fins (those already mentioned are single, and are placed on the central line of the body) which evidently represent the arms and legs of man. The hinder pair of these is not unfrequently situated nearly as far forwards as the other; this is the case in the perch, as well as in the mullet, of which a sketch is given in fig. 36. The single fins arranged on the central line, are the first and second dorsal, *d* 1 and *d* 2, the caudal or tail-fin, *c*, and the anal fin, *a*; at *v* is seen one of the ventral fins, which correspond to the legs; and above this is shown one of the pectoral fins, which are analogous to the arms. These fins are of little use in propelling the

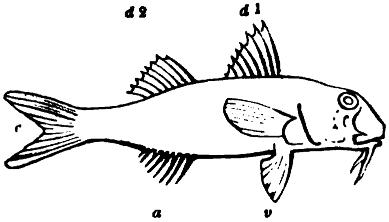


FIG. 39.—BEARDED MULLET.

fish through the water; but they give great assistance in raising or lowering it, and in changing its direction. Sometimes one or both pairs of them are absent.

100. Although Fishes breathe by gills instead of by lungs, these gills are connected with the mouth, so that the water which passes over them is received into it, in the same manner as the air is in the higher Vertebrata. This is a character which distinguishes the position of the gills of fishes, from that of the corresponding organs of any of the inferior tribes. They are lodged in a cavity on each side of the throat; and this cavity opens outwardly, either by one large valve-like aperture on either side, or by several; through these apertures, the streams of water, which have been taken in by the mouth, and forced over the gills by the action of its muscles, make their exit.

101. The bodies of Fishes are usually covered with scales or plates, which have sometimes a bony hardness, and which, in some species of fishes that do not now exist alive, appear to have been even of the density of enamel. Thus we have a sort of transition to the external skeletons of the Invertebrated animals. And in this class also we not unfrequently find the internal skeleton so deficient in the stony matter from which bone derives its hardness, that it seems like cartilage or gristle; and in a few of the lowest species, we do not even find a distinct vertebral column. So that the change of character from the Vertebrated to the Invertebrated series is a gradual, and not an abrupt one; and would probably be found to be still more gradual, if we were acquainted not only with all the forms of animal life which now exist, but also with those which have existed in ages long gone by, and are now extinct.

102. In the *Articulated* subdivision of the animal kingdom, we meet with differences no less remarkable than those we have already seen. In some we find the body furnished with articulated members or legs, which constitute its instruments of motion, as in the *Sandhopper* (Fig. 40); and it is in these that the organs of sense are best developed, and that those ganglia of the nervous system which the head contains, exert the greatest influence over the rest. Sometimes, on the contrary, as in the leech, there are no

jointed members, the nervous ganglia are but little developed even in the head, and they all have nearly the same functions. Hence we might subdivide this group into two,—those which possess articulated members,—and those which are destitute of them. Each of these is again subdivided into classes.

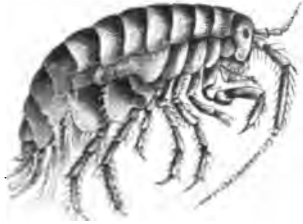


FIG. 40.—SANDHOPPER.

103. In the highest division of the Articulated series, we easily recognise, as forms quite distinct from each other, the *Insects*, the *Spiders*, the *Crustaceous* animals (crabs, lobsters, &c.), and the *Centipedes*. The class of INSECTS is distinguished, for the most part, by the presence of wings, but to this there are exceptions. It includes those of the higher Articulata, which breathe air by means of air-tubes distributed through the body (§. 320), which have no more than *six* legs, and whose body, in its perfect form at least, manifests a division into three distinct parts—the *head*, *thorax*, and *abdomen* (Fig. 41). To the thorax alone are attached the six legs, as well as the wings; and its cavity is principally occupied by the muscles that move them: the abdomen contains the organs of digestion and reproduction, as in vertebrated animals. In the greater part of this class, the young animal comes forth from the egg, in a condition very different from that which it is ultimately to possess; and it undergoes a series of changes, after the last of which only it presents the form of the perfect insect. In some tribes, the general form is the same from the first, and the wings

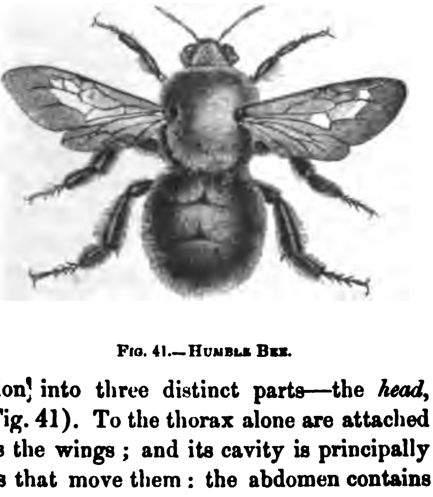


FIG. 41.—HUMBLE BEE.

are the only parts deficient; these gradually make their appearance, and the insect is then perfect. Such is the case with the grasshopper and cricket kind; and a change of this kind is termed an *incomplete metamorphosis*. But in general, the change of form is much greater; for that which the egg produces has a form quite unlike that of the perfect insect, and much more resembling the lower classes of Articulata.

104. The caterpillar or maggot of many Insects is completely destitute of legs; and where it does possess feet by which it may crawl, these are merely fleshy projections, and are not jointed members. The segments or divisions of the body are all equal, or nearly so, as in the worm tribe; and in its habits and mode of life, the *larva* (as it is termed) is entirely unlike the perfect insect. It is extremely voracious, and increases rapidly in size; and during this increase, its skin is several times thrown off, and a new one formed, better adapted to its advancing growth. When it has attained its full development as a caterpillar, it undergoes a very remarkable change, previously to which it usually forms a protection for itself; either by weaving a silken thread of its own spinning, into a case or cocoon (as is done by the silk-worm); or by gluing together bits of stick, straw, or dead leaves, as is done by many other insects; or by burying itself in the ground, as do most of the beetle tribe. Beneath this protection it undergoes its first metamorphosis into the state of *chrysalis* or *pupa*; in which it remains completely or partially motionless, and

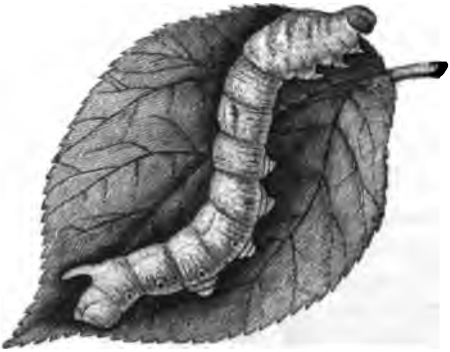


FIG. 42.—SILK-WORM.

FIG. 43.—CHRYSALIS OF THE SILK-WORM.

takes no food, but lives upon the store which had been deposited in its tissues whilst yet in the larva condition.

105. The period during which it remains in this state is not, however, one of real inactivity; for changes of a very important nature are taking place within the body. The wings and other parts characteristic of the perfect insect are being developed; and preparation is thus being made for its coming forth into the world, as if after its re-entrance into the egg, in a complete state. In this condition only it can reproduce its kind; and the fertilization and deposition of the eggs, together with the preparation of a residence for the young, constitute the great business of the perfect Insect; which, in many instances, takes no nourishment from the time that it undergoes its last metamorphosis. Those insects, in whose development these three stages are distinctly marked, are said to undergo a *complete metamorphosis;* but there are some among these, in which the chrysalis does not completely lose its power of motion; and whose history, therefore, has a certain resemblance to that of the insects whose metamorphosis is incomplete. These general characters of the *larva*, *chrysalis*, and *perfect* states of the Insect, will hereafter be not unfrequently referred to.

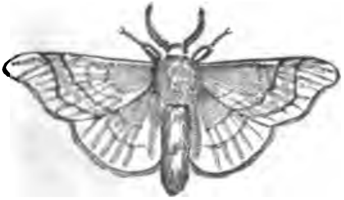


FIG. 44.—SILK-WORM MOTH.

106. The animals of the class ARACHNIDA, which includes the *spiders*, *scorpions*, and *mites*, are, like insects, articulated, breathing air, and possessing legs, but the number of these legs is never less than *eight;* there is an entire absence of wings, and the head is united with the thorax, so that the body seems to be formed of two principal divisions,—the *cephalo-thorax* (as it is termed),—and the *abdomen*. In Fig. 46 we have a representation of the arrangement of the parts contained in these cavities. At *c t* is seen the cephalothorax opened from below, and giving attachment to the legs; at *m* is shown the place of the mandibles or jaws; at *p* is seen one of the palpi, which are appendages to the mouth; *p a* is the foremost leg; *t*, the large

nervous mass, from which the legs are supplied; *a*, the collection of ganglia supplying the abdomen; *a b*, the abdomen; *p a*, the respiratory chambers; *s*, the stigmata or openings into these; *l*, the leaf-like folds within them (§. 323); *m a*, the muscles of

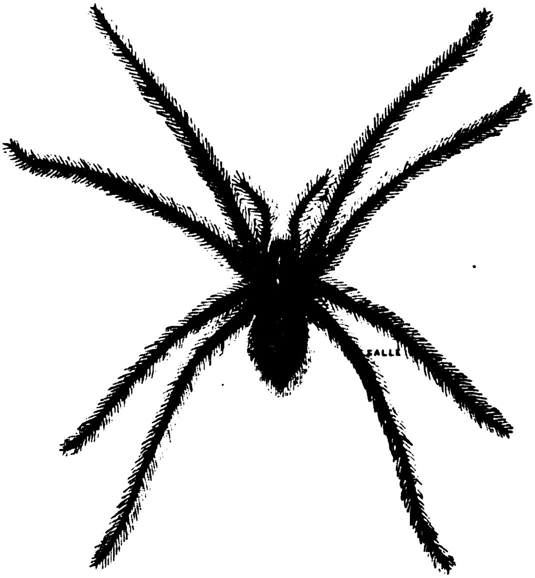


FIG. 45.—HOUSE-SPIDER.

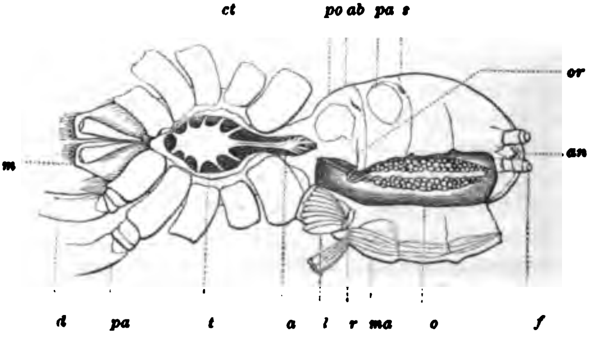


FIG. 46.—ANATOMY OF SPIDER.

the abdomen ; *a n*, the termination of the intestine ; *f*, the spinnerets ; *o*, the ovaries ; and *o r*, the opening of the oviduct.

107. The class of CRUSTACEA, of which the *crab*, *lobster*, and *crayfish* are the best known forms, differs from both the preceding, in being adapted to breathe by means of gills, and thus to reside in or near water, instead of being tenants of the air. Moreover the body is enclosed in a hard covering, which generally contains a good deal of carbonate of lime, and which is thrown off at regular intervals. This covering also encloses the members, which are never less than ten in number, and are frequently more numerous. There is great

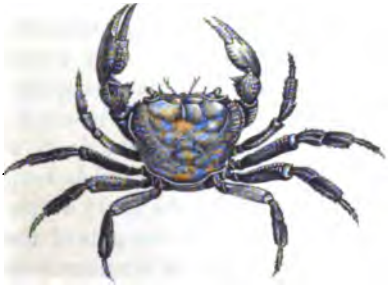


FIG. 47.—THELPHUSA.

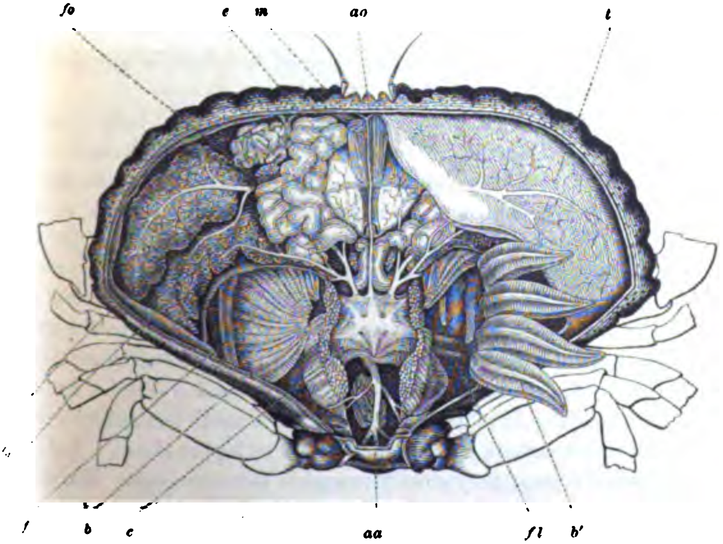


FIG. 48.—ANATOMY OF A CRAB.

variety of form among the animals of this group, which is altogether one of great interest. In the *Crab* tribe, the head, thorax, and abdomen are all drawn together, as it were, into one mass; and the general arrangement of the organs it contains is exhibited in the preceding figure, which shows them nearly as they are found to lie, when the upper part of the shell, or *carapace*, is removed. At *t* there is left a portion of the membrane which lines the carapace and covers in the viscera. On the central line, at *c*, is seen the heart, which in the Crustacea is large and powerful in its action; from it there passes forwards the artery *a o*, which supplies the eyes and the front of the body; whilst the artery *a a* passes to the lower and hinder parts; at *b* are seen the gills of the left side in their natural position; whilst at *b'* are seen those of the right side, turned back to show their under surface, and to disclose the lower portion of the shell, *f l*. At *e* is seen the stomach, situated close behind the mouth; and at *m* are pointed out its powerful muscles, by the action of which the food is ground down. The convoluted intestine is seen on either side of the stomach; and the space between this and the edge of the shell, is occupied by the very large liver, *f o*.

108. In most of the Crustacea, however, the body is more prolonged. In some, as the *Lobster*, there is an indication of a division of the body into three parts, representing the head, thorax, and abdomen of insects; whilst in others, as the *Sand-hopper* (Fig. 40), the rings or segments are almost as similar to each other, as they are in the centipede tribe. There is no class in which we find the same parts exhibiting so great a variety of forms, and rendered subservient to so many uses. In the crab and lobster the members of the first pair are not used for walking, but form the claws or arms, by which the food is seized. In the *Cray-fish*, (Fig. 51) this variation of form is much less remarkable; and these members may be used either as legs or claws. And in the *Sand-hopper*, they closely resemble the other legs. But this is a very small part of the diversity just alluded to. Most of the Crustacea, like insects, come forth from the egg in a state very different from their adult form; and afterwards undergo a series of changes, which are in some instances so remarkable as

to approach the complete metamorphoses of insects, and which end in the production of the complete form. An early form of the common crab, at a time when it is of the minute size indicated on the scroll, is shown in Fig. 49.

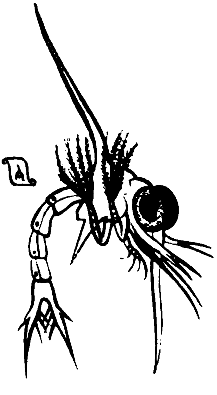


Fig. 49.—Early Form of a Crab.

109. Now the immature Crustacea of different tribes bear much more resemblance to each other, than do the forms into which they are ultimately to be developed; and the differences they afterwards present are chiefly due to a variety in the amount of growth, which the different parts undergo. Thus in the crab, the thorax is developed at the expense of the abdomen or tail; in the lobster and cray-fish, the hinder part of the body is developed at the expense of the front. This variation in the development of the same parts is most remarkably shown in regard to the members connected with the segments forming the head and the front of the thorax. In the *Limulus* or king-crab, of which the under surface is shown in Fig. 50, these members, *p*, are fully developed around the mouth *b*; and they are so formed, as to serve either as legs or claws; whilst the joints nearest the mouth act the part of jaws. Beneath the hinder portion of the body are appendages, *a b*, which support the gills. But, as may be readily supposed, these *feet-jaws* do not perform the functions of movement or of

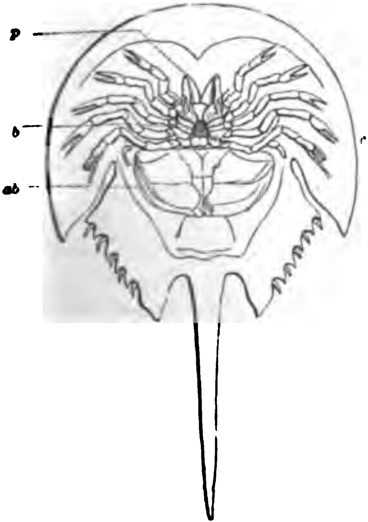


Fig. 50.—Limulus.

mastication so completely as they would do, if they had either to perform, and were particularly adapted for it; and accordingly we find, in the higher tribes of this class, that this separation of function does take place; and that, whilst the members nearest the mouth are converted into jaws, those belonging to the trunk serve as legs and claws.

110. This is the case in the *Cray-fish*, the several parts of which are shown in the accompanying figures. In Fig. 51 is

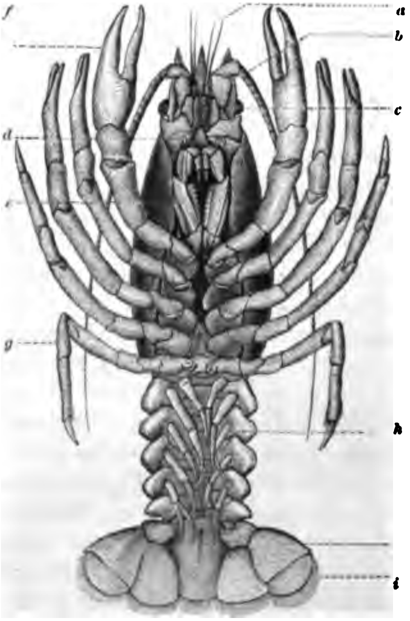


FIG. 51.—CRAY-FISH.

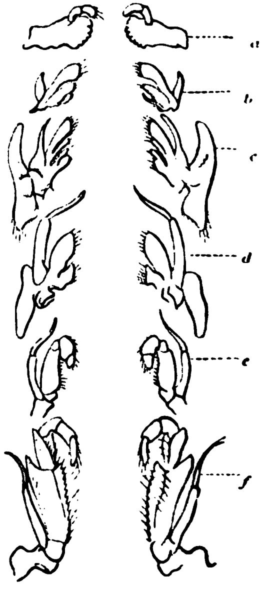


FIG. 52.—MASTICATORY APPARATUS.

seen the under side of the animal, exhibiting the general arrangement of its members. The letters *a* and *b* point to the two pairs of *antennæ* or feelers, which many of the Crustacea have, in common with insects; at *c*, are the eyes, and at *d* the imperfect organ of hearing. At *e* are seen the external feet-jaws, which correspond to the legs of the limulus; whilst between *f* and *g* are situated the five pairs of true legs developed from the thorax. At *h* are shown the false legs beneath the abdomen; at *j* the termination of the intestinal canal; and at *i*, the broad fin-like expansion of the tail, by which chiefly the animal propels itself through the water. In the adjoined series of figures, are represented the various forms of the feet-jaws; by which it is seen that there is a gradual change, from before backwards, into the character of the other limbs. The first of the six pairs, *a*, constitute the chief *biting* jaws or *mandibles;* the second and third pairs, *b* and *c*, are also termed jaws; whilst the three remaining pairs, *d*, *e*, and *f*, which approach the legs in form, are termed auxiliary jaws.

111. When we come to consider the instruments of motion in the different classes more in detail, we shall meet with many examples of this kind of adaptation of the same elementary parts to a variety of purposes; but there is probably no class which presents so great a diversity within itself, as does the one we have been considering.

112. From the Crustacea we pass back to another class of the higher group of Articulata, adapted to breathe air, and to inhabit the land—the MYRIAPODA or *Centipede* tribe. Both these names are derived from the great number of their legs, which often amount to 60 pairs or even more. In this class we see a more perfect equality of the segments or divisions of the body, than any others among the higher Articulata present; and the similarity is scarcely less complete in the internal arrangement, than it is in the external form. In its lower tribes, the legs are so weak as scarcely to be able to sustain the body, which moves, therefore, partly in the manner of a worm. The animals of this class undergo no proper metamorphosis; but there is a considerable addition to the number of their segments and legs, after they have come forth from the egg.

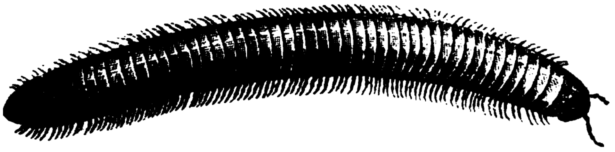


FIG. 53.—IULUS.

113. In this portion of the Articulated series we must place a small but very remarkable group of animals, which were for some time associated with the Mollusca; their bodies being enclosed in shells, which do not fit closely around them, nor give more than a general protection to their members. This group is the *Barnacle* tribe, forming the class CIRRHIPODA, or tendril-footed animals. They agree with the lower Mollusca, in being fixed to one spot during all but the earliest period of their lives; the shell being sometimes attached by a long membranous or leathery tube, as that of the *Barnacle* (Fig. 54); and sometimes being itself fixed on the surface of a rock, or on another shell, as is that of the *Balanus* or acorn-shell. In both cases, the form and structure of the animal are essentially the same. When taken from the shell (in which it lies doubled up, as it were,) and spread out, its articulated nature is evident, by its division into segments, and by the regularity of the arrangement of their tendril-like appendages. These are not formed like legs, since they could be made no use of, the animal being incapable of moving from place to place; but they serve to produce currents in the surrounding water, by which food is brought to the mouth, and the blood is submitted to the influence of a fresh supply of air. (§. 298.) The nervous system of this class is formed precisely upon the plan of that of the Articulated in general (§. 71): and if any doubt could have remained as to its true place in the series, it is removed by the knowledge of the fact, that the animals composing it bear a strong resemblance, in their early condition, to some of the lower Crustacea, possessing eyes and legs, and swimming freely about; and that they attain their adult form by passing through a series of metamorphoses, in which they

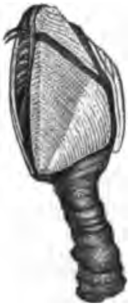


FIG. 54.—SHELL OF THE BARNACLE.

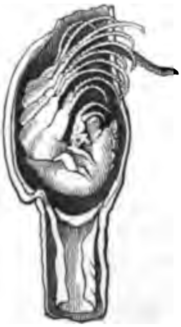


FIG. 55.—BODY OF THE BARNACLE.

lose their eyes and legs, and become fixed for the remainder of their lives.

114. We now pass to the lower division of Articulata, in which the body possesses no jointed members; and the animals belonging to this group are for the most part included in the class of ANNELIDA, the *Leech* and *Worm* tribe. We here find the body enveloped,—not in a hard casing, formed in distinct pieces united by a flexible membrane,—but in a skin which is altogether flexible, and which gives little indication of a division into segments. The reason of this is evident. In the Articulata possessed of distinct members, the act of movement or progression is accomplished for the most part by these only; and the more they are developed, the less flexible do we find the body. The same principle has been already pointed out in regard to the internal skeleton, or spinal column, of Vertebrata. In Fishes, the motion of the body through the water is accomplished chiefly by its own vibration from side to side, and the spine is very flexible. (§. 98). In Birds, on the other hand, where the motion of the body through the air is effected by the stroke of its wings, the trunk is very strongly knit together, in order to give a firm attachment to the powerful muscles by which they are moved (§. 88). Hence in the Articulated series, it is natural that we should expect to find the covering of the body most soft and flexible, in those lowest tribes, in which there are no separate members for its propulsion.

115. The Class ANNELIDA includes several distinct tribes; which all agree, however, in the long worm-like form of the body, and in the similarity of the different ganglia of their nervous system. The highest tribe is adapted to live in air as well as in water; this includes the *Leeches* and *Earth-worms*, in both of which we see the division of the body into rings tolerably well marked. They breathe by means of a series of little sacs or bags

FIG. 56.—LEECH.

which are placed along each side, and which open directly outwards, so as to receive either air or water. It is remarkable that, in these and some other Annelida, the blood should have a reddish or port-wine colour, instead of being pale or white, as in the Articulata in general (§. 226); but this colour is not the consequence of any real resemblance between the blood of these Annelida, and that of Vertebrata; as will be explained hereafter (§. 226). Most of the inferior tribes of this class are purely aquatic; and they breathe by gills, which form tufts that are disposed on various parts of the body. In the *Nereis*, or Sea-centipede, (Fig. 57), these tufts are arranged regularly on the several segments; and the animal can swim by the motion that it gives them; besides which it has a kind of bristle-shaped appendage, that seems like an undeveloped leg, which assists it in crawling. But there are others of these marine-worms, that form a tubular shell, in which they reside during the greatest part of their lives; and in these the gills, if disposed along the body, would have been removed from the access of water; they are therefore arranged round the head, often forming (as in the *Serpulæ*, Fig. 58) tufts of great brilliancy and elegance.

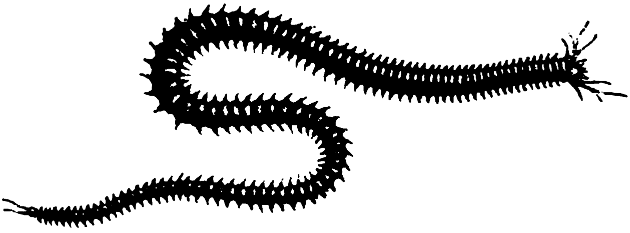


FIG. 57.—NEREIS.

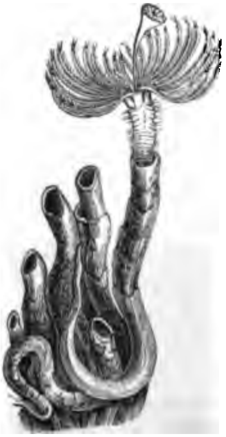


FIG. 58.—GROUP OF SERPULÆ.

116. From the Annelida we pass to animals which still re-

tain the same general plan of structure; but in which there is a yet greater simplicity of conformation. This is the case in the group of ENTOZOA, or *Intestinal Worms*, of which nearly all reside exclusively in the bodies of other animals. They possess, for the most part, the worm-like form; but their various parts cannot be so definitely distinguished. We first lose a distinct apparatus for the circulation of the blood; the nutritious fluid, where it has any proper movement, appearing to flow through channels excavated in the soft tissues. At the same time the nervous system becomes less and less distinct; and at last even the intestinal canal seems like a mere channel, hollowed out through the soft and almost jolly-like body. We observe, too, a still greater repetition of the same parts through the different segments; and a less dependence upon each other and upon the head. Thus the *Tænia*, or Tape-worm, may lose a large proportion of its joints, without appearing to suffer in consequence. In some of these parasitic animals, the worm-like form seems almost or completely lost; and there is some indication of the radiated type.

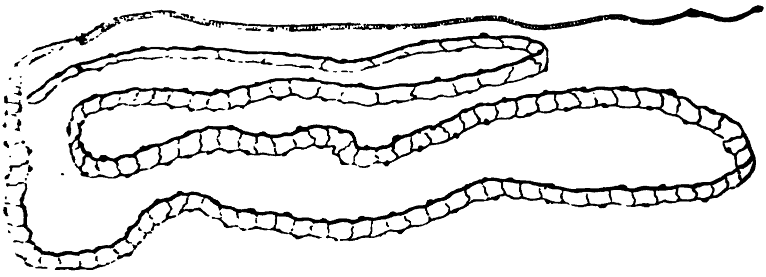


FIG. 59.—TAPE-WORM.

117. Another group that seems to belong to the lower portion of the Articulated series, is one of great interest to the microscopical inquirer; containing a variety of very curious animals, of such minuteness, that they can be only just discerned by the naked eye under the most favourable circumstances; and at the same time of such transparency, that their structure can be as completely made out, by the assistance of the microscope,

as if it were possible to dissect every part. This group, commonly known under the name of *Wheel-Animalcules*, now constitutes the class ROTIFERA; it was formerly confounded with other animalcules of much inferior structure, from which it is distinguished by the possession of various organs in which they are deficient, and especially by the arrangement of the *cilia* (minute vibrating hair-like filaments, that answer several very important purposes in the economy of the highest as well as of the lowest animals, §. 319, 329) into two or more wheel-like groups, situated on the head. The body of the Wheel-Animalcules is covered with a thin transparent membrane, which is sufficiently flexible to allow almost every kind of change of form. Sometimes it is stretched out lengthwise, like that of a leech, and then exhibits a distinct division into segments; and the animal is sometimes seen to walk, as the leech often does, by means of the suckers placed at the two ends of its body. Sometimes, on the other hand, the body is contracted into the form of a ball; but in general, its aspect is that shown in the figure, the tail being fixed by a kind of sucker to a solid body, and the wheels on the head being put into active motion, for the purpose of drawing in nourishment. The head bears two red spots, which seem to be eyes. Behind it is a curious apparatus for the mastication of the food,

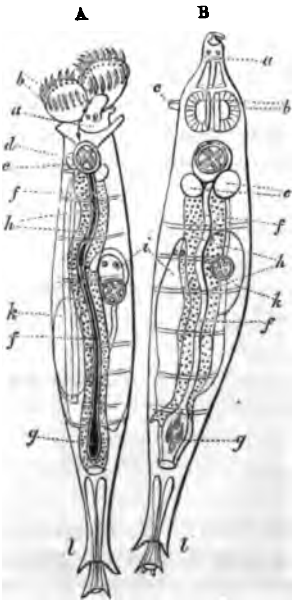


FIG. 60.—WHEEL ANIMALCULES; A, with the wheels expanded; B, with the wheels folded up and drawn in; *a*, the head with the eye-spots; *b*, the wheels; *c*, water-siphon; *d*, masticating apparatus; *e*, salivary glands; *f f*, intestinal canal; *g*, its dilated termination; *h*, glandular apparatus surrounding it; *i*, young ones nearly complete; *k*, eggs; *l*, tail.

the working of which can be distinctly seen; and after passing through this, the gullet enters the stomach, which is often very capacious. From the stomach, the intestinal canal passes directly backwards. Two or three eggs can often be seen within the body; and the transparency of the membranes of the egg, as well as of the body of the parent, allows the whole process of development (which often occupies only a few hours) to be watched without difficulty.

118. In the sub-kingdom, MOLLUSCA, we meet with a variety of form and structure no less remarkable; while the general type or plan already described (§. 73-78) is still found to prevail, more or less distinctly, through all its members. There is a complete absence, in the soft bodies of these animals, of anything like the jointed structure which is evident in almost every Articulated animal; and where arms, feet, or members do exist, they are destitute of any hard supports, and bear (as will presently appear) no real resemblance to the parts of the same name in the classes we have already considered. It is a character which is common to all the Mollusca, that the skin is thick and spongy in its texture; having muscular fibres interwoven in its substance, so that it can contract or extend itself in any part; and having the power of exuding shelly matter from its surface, in those species which form such a protection. This envelope, which is called the *mantle*, is very loosely applied round the parts which it contains; and there are generally large apertures in it, by which the water is admitted from without into the interior cavity, in which the stomach, intestines, &c., lie rather loosely. It is generally to the walls of this cavity that the gills are attached, which constitute the usual breathing apparatus of the Mollusca; and a continual current of fluid is made to pass over them, sometimes by the movements of the mantle itself, but most commonly by the action of the *cilia* with which they are covered.

119. As the Articulata are divided into two subordinate groups, according to the presence or absence of articulated limbs or members, so may we arrange the Mollusca in two sub-divisions, according to the presence or absence of a distinct *head*,—which has been already defined to mean, a projecting part of the body,

containing the mouth, or entrance to the digestive cavity, and also bearing the organs of sense, which guide the animal in the discovery and selection of its food. In the higher Mollusca, there is a distinct head, furnished with eyes, and sometimes with imperfect ears; but in the lower, the entrance to the digestive cavity or stomach is within the cavity of the mantle, and is guarded by no other organs of sense than the *tentacula*, or sensitive lips, which are sometimes prolonged into arms that serve to grasp the food. These are termed *acephalous*, or headless Mollusca; and among the lowest of them (§. 126), we even find a tendency to the union of several individuals into a compound structure, which is so remarkable a characteristic of the Polype tribe (§. 80).

120. It has been already stated, that *sluggishness* is the general character of this group; and we find no general definite provision for locomotion, but a particular adaptation of certain parts to meet the wants of each class. Thus, in the *Cuttle-fish* tribe, the *arms* that surround the mouth are nothing else than the tentacula of the lower tribes, very greatly prolonged. In the little *Pteropods*, that seem like the Insects of the ocean, the wing-like fins by which they swim, are only expansions of the mantle sideways. In the *Snails*, *Whelks*, *Limpets*, and other similar Molluscs, the *fleshy disc* on the under side of the body, upon which the animal crawls (§. 75), is formed by a simple thickening of the muscular structure in that part of the mantle. In the *Cockle* and other animals inhabiting bivalve shells, which move by means of a *foot*, that foot is merely a tongue-like fleshy projection, also formed by an increase in the muscular substance of the mantle in a certain part. In the *Oyster* and others of the same group, as also in the lowest class of headless Molluscs, there is no foot, or special organ of locomotion; but the animal is for the most part fixed to one spot during the whole of life; and the movements it may perform are chiefly due to the contractions of the mantle in general.

121. The highest group of Mollusca, in regard to the approach of several parts of its structure to that of Vertebrated animals, is the class of CEPHALOPODA, the *Cuttle-fish* tribe. This class re-

ceives its name from the peculiar arrangement of the arms or feet around the mouth, which is the characteristic of its members. Sometimes these arms are very broad, and united at their base into a kind of circular fin, as in the common *Octopus* or *Poulp* represented in the accompanying figure; and the body is then short and thick. In other instances the arms are short, and the body long and flexible, and furnished with a fin-like expansion behind, as in the *calamary* or *squid*. The common *Cuttle-fish* and its allies are destitute of any external protection; but they usually have a flat shell, commonly known as the cuttle-fish bone, enclosed in a fold of the mantle, and lying along the back. In the *Calamary*, this is horny in its texture, and is sufficiently flexible to offer no resistance to the action of the fin-like tail, by which the animal is propelled through the water, very much in the manner of a fish. Some of the Cephalopods now existing, however, and a still larger proportion of those which peopled our seas in past ages, were enclosed in spiral shells; and these shells, preserved

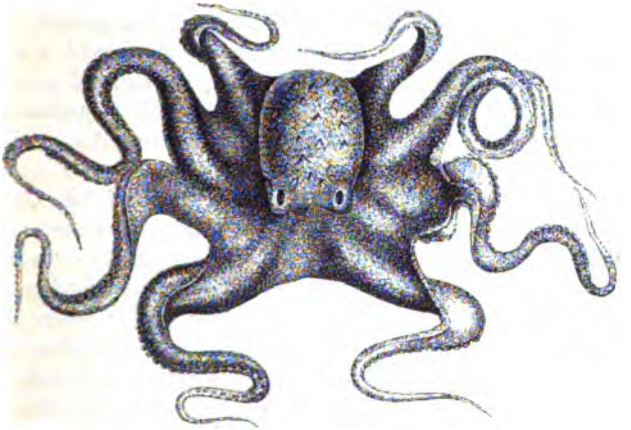


FIG. 61.—OCTOPUS OR POULP.

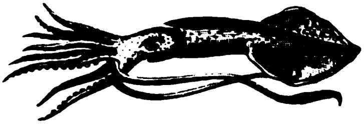


FIG. 62.—CALAMARY.

to us in a fossil state, constitute the *nautilites*, *ammonites*, *belemnites*, &c., which abound in many rocks. The Cuttle-fish are animals of considerable activity; their mouth is furnished with a horny beak, strongly resembling that of the parrot; and their arms are provided with a series of very curiously constructed suckers, by the action of which they can take a very firm hold of anything which they desire to grasp.

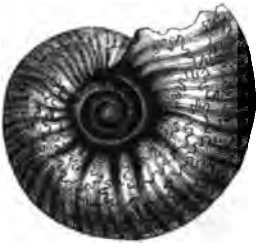


FIG. 63.—AMMONITE.

122. The class of PTEROPODA, or *wing-footed* Mollusca, consists of but few species, and the animals which it contains are all of them of small size; but the individuals are often very numerous, whole fleets of them being sometimes seen covering the ocean, especially in the Arctic and Antarctic regions, where they constitute one of the principal articles of food to the Whale. The general form of the body usually differs but little from that represented in Fig. 64. On either side, a little behind the head, the mantle is extended into a fin-like expansion; by the aid of which, the animal can swim rapidly through the water. The hinder part of the body is usually enclosed, more or less completely, in a shell, which is commonly of extreme thinness and delicacy. The head is not furnished with long arms, to grasp the food; but it has a number of minute sucking discs, by which it can lay firm hold of whatever it attacks; whilst its powerful rasp-like tongue is set to work upon it.

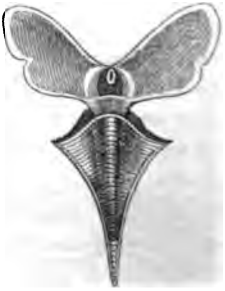


FIG. 64. HYALÆA.

123. The class GASTEROPODA, which is the next in order, contains those animals which, like the snail and slug, crawl upon a fleshy disc on the under side of their bodies. The greater part of them are inhabitants of the sea-shore, rivers, lakes, &c.; some have the power of swimming freely through the open sea; and the proportion of those that breathe air and live on land, is com-

paratively small. The general structure of the animals of this group has been already described (§. 76). Some of them form shells, whilst others are destitute of them. The shells are composed of a single piece, or are *univalve*, excepting in one tribe; and they have usually more or less of a spiral formation. The animals of this class all possess a distinct head; and this is generally furnished with eyes, as well as with tentacula. They have often a powerful masticating apparatus, and are voracious in their habits; some of them feed upon vegetable matter, others upon animals.

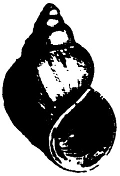


FIG. 65.—SHELL OF PALUDINA.

124. The Acephalous Mollusca are divided into two groups,—those which form shells, and those which do not. The former are termed CONCHIFERA, or *shell-bearing* animals; and this class includes all the Mollusca that form a shell composed of two parts or valves fitted together (which shell is termed *bivalve*), as well as some others whose general structure is the same, but whose shell is formed in several pieces, or *multivalve*. The shell in these animals sometimes attains an enormous size; thus the shell and animal of the *Tridacne gigas*, or giant clamp-shell of the East Indies, have been known to weigh as much as 5 or 6 cwt. The two valves of a bivalve shell are connected by a *hinge*, where they are united by a ligament, which, by its elasticity, holds them apart while it keeps them together. This is their usual condition when the animal is alive; and in this manner, the water which is required for their respiration, and also to convey their supply of food, has free access to the internal parts. But when the animal is alarmed, and desires to close the shell for its protection, it does so by means of a muscle which stretches across from one valve to the other, and which, by con-

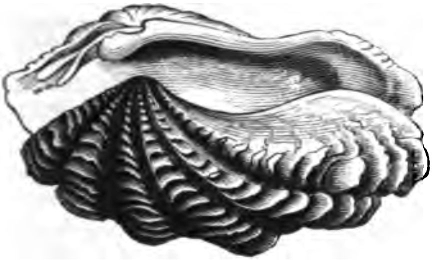


FIG. 66.—TRIDACNE.

tracting, draws them together. Each valve is lined by one-half or lobe of the mantle. In the higher tribes of the class, these halves are united along their edges, leaving apertures for the ingress and egress of water (which are sometimes prolonged into tubes), and another for the foot. But in the *Oyster* and its allies, which have no foot, or a very small one, the halves of the mantle

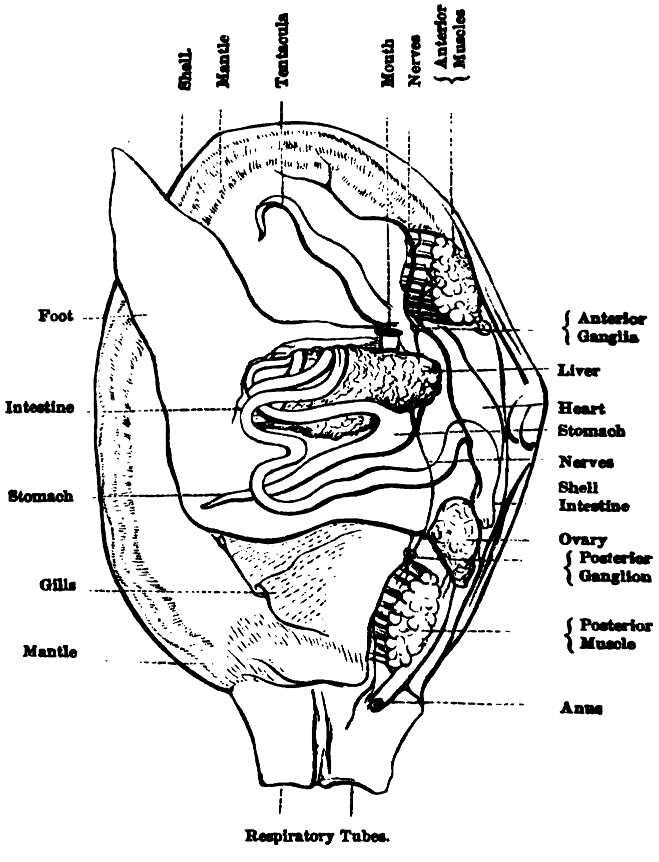
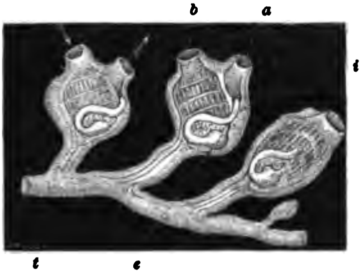


FIG. 67.—ANATOMY OF AN ACEPHALOUS MOLLUSC.

are quite disunited, and the water has free access to all the viscera included within the shell.

125. The accompanying figure gives a general idea of the arrangement of the organs in one of the higher acephalous Mollusca, the *Mactra*, which is among those having two muscles for the drawing together of the valves. The upper end, as represented in this figure, is that which is considered as the anterior end or front of the animal, being that nearest which the mouth lies; and the posterior extremity (the lowest in the figure) is that at which the intestinal canal terminates, and at which the respiratory tubes are formed. Near the anterior muscle, we find the mouth, or entrance to the stomach; it is furnished with four riband-shaped tentacula, of which one is seen in the figure; and these seem to possess peculiar sensitiveness. Near the mouth lie the anterior ganglia of the nervous system, which correspond to the brain of higher animals; and these are connected by long cords with the posterior ganglion, which lies near the posterior muscle. The stomach, intestines, and liver, occupy the central portion of the cavity of the shell; and the intestinal tube is seen to pass backwards, terminating near one of the canals or siphons, which also carries out the water that has been taken in through the other, for the purposes of respiration. The figure also shows the large fleshy foot, by which this animal can move itself along the ground, or bore into sand or mud. The heart and circulating system are less complete than in the Gasteropoda; but are far higher in character (as are most of the other parts of the nutritive apparatus) than the corresponding parts in Articulated animals, in which the apparatus for locomotion so much predominates.

126. The class of TUNICATA includes the lowest of the Acephalous Mollusca, which are destitute of the power of forming a shell, but which have the outside of the mantle condensed into a tough leathery or cartilaginous *tunic*, from which their name is derived. Many of them live separately, and have the power of freely moving through the water. Others associate together into a compound mass; of which, however, the individuals are not connected by any internal union. But others form really



68.—Social Ascidiæ.

compound structures, like those of the Polypes (§. 131); each individual being able to live by itself alone, but being connected by a stem and vessels with the rest. The general structure of the individuals is the same, however, in the single and in the composite animals of this class, and may be understood from the accompanying figure. The cavity of the mantle possesses, as in the former instance, two orifices; by one of which, *b*, a current of water is continually entering, whilst by the other, *a*, it is as continually flowing out. These orifices lead into a large chamber, the lining of which, folded in various ways, constitutes the gills; and at the bottom of this chamber lie the stomach, *e*, and the intestinal canal, *i*, which terminates near the aperture for the exit of the water. All these parts are covered with *cilia*, by the action of which a continual stream is made to flow over the gills, and to enter the stomach; and the minute particles, which the water brings with it, and which are adapted to serve as food, are retained and digested in the stomach. Even these animals, fixed to one spot during all but the early part of their lives, and presenting but very slight indications of sensibility, possess a regular heart and system of vessels; and these vessels form part of the stem, *t*, by which the compound species are connected.

127. This class is one of particular interest to the naturalist; since many of the animals it contains bear so strong a resemblance to certain of the higher Polypes, that it is difficult to separate them;—thus showing a connexion between two groups apparently quite distinct, and exemplifying the principle that the different classes are not separated by wide gaps. This connexion is further manifested, in the extension of these compound structures, by a process resembling that of the *budding* of plants.

128. In the Radiated classes, the varieties of structure which present themselves, even among those which show the circular arrangement of the organs most distinctly, are extremely remarkable; and they are such as to make it difficult to define the classes by any single definite characters. Thus the first class, that of ECHINODERMATA, receives its name from the *prickly character* of its covering, which is evident enough in the *Star-fish* (§ 79) and *Sea-Urchins;* but there are other animals, sufficiently resembling these in general structure to be united in the same class, which have a body entirely soft,—namely, the *Holothuriæ*, commonly termed *Sea-Cucumbers*. This class ranks the highest among the Radiata, in regard to general complexity of structure. The skeleton of the star-fish, sea-urchin, and other animals resembling them, is formed of a great number of pieces, very regularly arranged and united together (Fig. 70); but these pieces are for the most part but repetitions of one another; and the different portions have not that variety of uses which we see in higher animals. With the exception of the tribe of *Crinoidea* or lily-like animals, of which there are very few now existing, but which were very abundant in former ages, all the animals belonging to this class are unattached, and are capable of moving freely from place to place. Their motions are very sluggish, however, and are principally effected by means of an immense number of minute tubular feet, furnished with suckers at their extremities, which can be projected from almost any

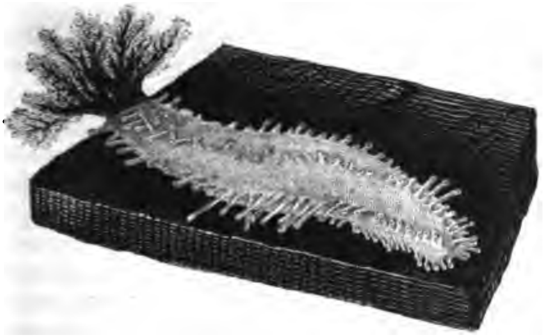


FIG. 69.—HOLOTHURIA.

part of the body. These are seen in rows on the under side of each arm of the Star-fish; they are put forth through rows of very minute apertures in the shell of the Sea-Urchin (commonly termed the sea-egg); and they are also arranged in rows on the surface of the body of the Holothuria, as seen in Fig. 69.

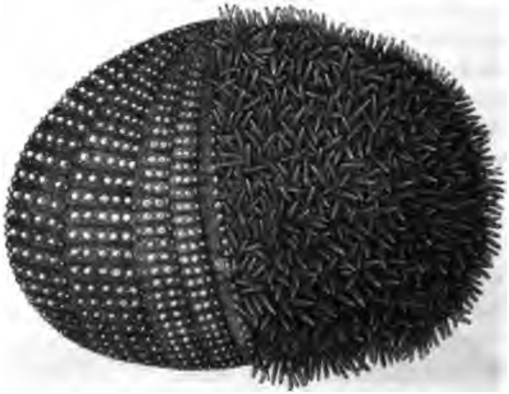


FIG. 70.—Shell of Sea-urchin; on the right side, covered with spines; on the left, the spines removed.

129. The radiated arrangement is very evident in the whole bodies of the *Star-fish* (Fig. 16), and *Sea-Urchin;* but in the Holothuria it is nearly confined to the parts about the mouth; which, however, exhibit it so completely, that such an animal cannot be mistaken for one of the Articulated series, even though, as sometimes happens, the body is prolonged into a worm-like form. The digestive apparatus in this class has usually a high degree of complexity. In the Sea-Urchin and Holothuria, there is a regular stomach and intestinal tube; and the latter terminates by a distinct orifice, at a distance from the mouth. The circulating apparatus, however, is imperfect, the blood not being impelled by a distinct heart; still, however, it moves through proper vessels, and not through mere channels in the tissue. There is also a regular provision for respiration; the water being admitted to the interior of the shell, in order to convey air to the fluids of the body. In the Star-fish, however, the body is very much flattened; and the stomach, instead of having a separate intestinal tube with a distinct orifice, is a mere bag with

a single aperture, which serves both to take in food, and to cast forth the indigestible remains. This character will be found to prevail among all the inferior Radiata. The amount of sensation possessed by the animals of this class, has been already noticed (§. 79).

130. In the second group of Radiata, forming the class of ACALEPHÆ or *sea-nettles*, the body is entirely soft and jelly-like; containing so small a quantity of solid matter, that, when taken out of the water, so that its fluid drains away, there is scarcely anything left. Hence, the animals of this class are commonly termed *jelly-fish*. They derive their other name of Sea-Nettles from the stinging power which most of them possess. They are formed to float freely through the water; but they do not in general possess any means of actively propelling themselves through it. The radiated arrangement is very regularly preserved in some of this group, whilst it is less evident in others. The accompanying figure represents one of the *medusa* tribe, as seen floating in water. The umbrella-shaped disc above contains the stomach, which is placed in the centre, and which opens by a single orifice or mouth, directed downwards. Around the stomach are four chambers, in which the eggs are prepared. The mouth is surrounded by four large tentacula, which bring to it the necessary supply of food; and other tentacula are seen, in this species, to be hanging from the edge of the disc. In the edge of this disc, the nutritious fluid, which flows in channels excavated out of the soft tissues, seems to be exposed

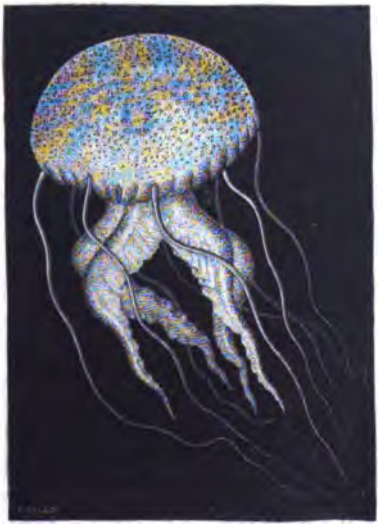


FIG. 71.—PELAGIA.

to the influence of the surrounding water; but nothing like a heart, or a regular circulation, can be discovered.

131. We pass from these to a very remarkable group, which, though low in organisation, is second to none in regard to its importance in the economy of Nature,—the class of POLYPIFERA, or *coral-forming* animals. This includes several tribes, which differ from one another in structure, to such a degree as almost to require to be distributed into three separate classes. The simple conformation of the little *Hydra*, or fresh-water polype, has already been described (§. 14.); and this may be taken as the type of a number of compound structures, more or less resembling that of the *Sertularia* here delineated. Each of them consists of a stem and branches, of a horny texture; and on the sides or ends of these are a number of little cells or bell-shaped chambers, with their mouths upwards, in every one of which is a polype, bearing a strong resemblance to the Hydra. Each of these polypes is capable of living independently of the rest, obtains its nourishment by means of its own arms, and digests it in its own stomach; but all are connected by a set of vessels that pass along the stem and branches, in which a kind of circulation takes place, that strongly reminds us of that of the compound Tunicata (§. 126). This plant-like structure extends itself by budding; new branches are formed from those previously existing; these are enlarged at a certain

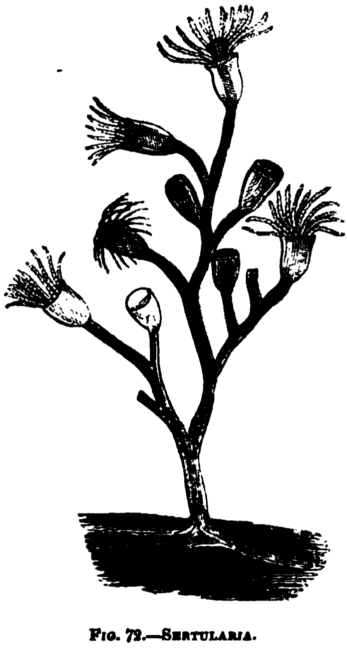


FIG. 72.—SERTULARIA.

point into cells, and after a time polypes make their appearance in them.

132. It is not, however, by animals of this very simple structure, that the massive stony fabrics are built up, which constitute the coral islands of the Pacific Ocean, and of which a large portion of our limestone rocks seems to be composed. These are constructed by animals that are formed upon the same plan with the *Sea-Anemone*,—a plan which is higher than that of the Hydra, inasmuch as we find the interior of the body containing other cavities beside the stomach; which cavities are destined to form and prepare the germs, and are analogous to the four ovarial chambers of the Medusa (§. 130). In Fig. 73, we have a representation of the Sea-Anemone, as seen from above; showing its mouth in the centre, surrounded by its numerous radiating tentacula; these are often brightly coloured, and give to the animal the appearance of a beautiful flower. In Fig. 74, a similar animal is represented, cut open to show its interior. The mouth is seen to open into a rounded stomach, *a*, which has no second orifice; and around this stomach there is a series of radiating membranous partitions, which divide the space intervening between it and the outer covering of the body into numerous chambers, *b*. The Sea-Anemone itself, like the Hydra, is a solitary animal, capable of shifting its place at will; and it forms no stony skeleton or support.

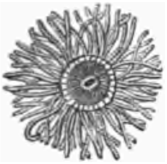


FIG. 73.—SEA-ANEMONE SEEN FROM ABOVE.

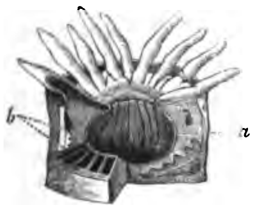


FIG. 74.—SECTION OF SEA-ANEMONE. *a* cavity of stomach, *b* surrounding chambers.

133. But there are other animals of the same general structure, which have the power of depositing stony matter in the membrane of their base or foot, and in the membranous parti-

tions between the chambers; and this stony deposit forms a *coral* or *madrepore*, such as is shown in the accompanying figure. The particular arrangement of the radiating plates of the madrepore (shown at the top of each stem) is the result of the form of the soft structures by which it was deposited; and wherever we see a structure of this kind in coral, whether upon a large or a small scale, we may infer that it was formed by an animal nearly allied in structure to the Sea-Anemone. Of the stone-depositing coral-animals, a large number are often associated in a compound structure, as in Fig. 76; this consists of a stony tree-like stem and branches; but instead of the soft animal matter being contained in its interior, as in the preceding case, it forms a kind of flesh that clothes the surface, and connects together the different polypes.

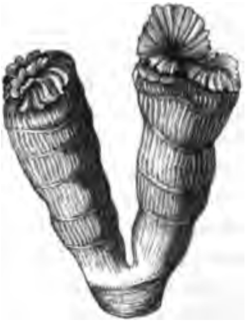


Fig. 75.—CARYOPHYLLIA.

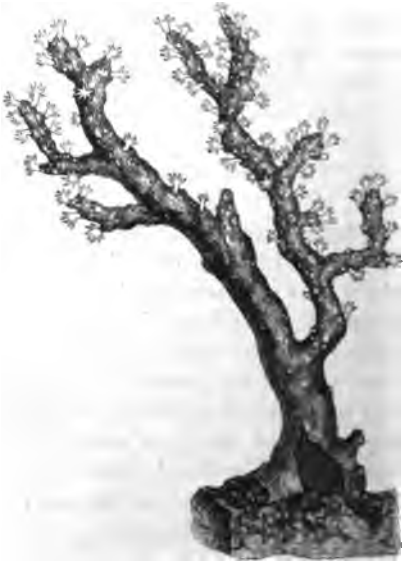


FIG 76.—STEM OF CORAL.

134. Some of the stony corals, however, are formed by polypes of a higher conformation; none of which have yet been discovered in a separate condition. Our example must therefore be taken from one of the compound structures found on our own coasts;

which is so transparent, as to enable all its parts to be distinctly seen. This polype is inclosed in a horny cell like that of the Sertularia; and has a moderate number of arms fringed with *cilia*, by the vibrations of which, rather than by the movement of the arms, a current of water is made to enter the mouth (*a*, Fig. 77). This is situated, as in other polypes, in the middle of the circle of arms; and it leads, by a large funnel-shaped tube, to a gizzard, *b*; in which the particles of food that enter it are ground down, by the action of its muscular walls, and of the tooth-like processes that line it. Below this gizzard is the true digestive stomach, *c*, around which the rudiment of a liver may be traced; and from this stomach there passes upwards an intestinal tube, which terminates by a distinct orifice at *d*, on the outside of the circle of arms. The digestive apparatus is evidently formed, therefore, upon a much higher plan in these animals than it is in the other polypes; and it is very interesting to observe, in their general structure, an approach, on the one hand, to the class Rotifera in the *Articulated* series, to some forms of which they bear a very strong resemblance; and also to the Tunicata among the *Molluscous* division, with which they are associated by some naturalists. Like the former, the polypes of this group are, for the most part, extremely small; so that their structure can only be discovered with the microscope.

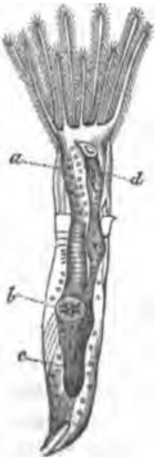


Fig. 77.—Bowerbankia. *a*, œsophagus; *b*, gizzard; *c*, stomach; *d*, orifice of intestine.

135. Some of the compound Polypes are connected, not by a regular stony or horny stem, but by a sponge-like mass; and its resemblance to these, in regard to whose animal character there can be no doubt, is one of the most satisfactory reasons for placing the class of Porifera, or the *Sponge* tribe, in the animal kingdom. With the general structure of the common sponge every one is acquainted. It consists of a net-work of horny, elastic fibres; but this is only the *skeleton* of the animal; for in

the living state, this net-work is covered with a gelatinous flesh, so soft that it drains away when the sponge is taken out of the water. The mass is traversed, however, by a great number of canals; which may be said to commence in the small pores upon its surface, and which discharge themselves into the wide canals that terminate in the large orifices or vents, which usually project more or less from the surface of the sponge. Through this system of canals, there is continually taking place, during the living state of the animal, (if animal it may be called,) a circulation of water, which is drawn in from without, through the minute pores, then passes into the large canals, and is ejected in a constant stream from the vents. Of the immediate *cause* of this movement, no satisfactory account has yet been given; no *cilia* can be seen, with the most powerful microscopes, to line the canals; and it is certain that no movement of the sponge itself has anything to do with it. But the *purpose* of this extraordinary circulation, is evidently to convey to the animal the nutriment which it requires, and to carry off the matter which it has to reject. No distinct indications of sensation, or of power of voluntary motion, have been seen in the sponge; so that it has no definite claim to a place in the animal kingdom, beyond that which it derives from its analogies of structure, and from the movement of the germs by which it is reproduced. These, like the germs of the polypes, swim freely about for some time before fixing themselves, by the action of the cilia with which they are covered.

FIG. 78.—SPONGE.

136. No allusion has yet been made to the very interesting and important class which includes those *Animalcules* that do not belong to the class Rotifera. It seems impossible to arrange them under any of the great general divisions of the animal kingdom; for, whilst they appear to correspond in simplicity of structure with the lowest of the intestinal worms, or of the polypes, their variety of form is such, that they cannot be regarded as either articulated or radiated animals. Of this variety, some idea is

given by Fig. 74; although the number of different forms there represented is very small. They are beings of extreme minuteness, distinguishable only with the microscope; their bodies seem to be of jelly-like softness, though they are sometimes covered by a sheath of horny or even siliceous (flinty) matter; and their transparency is such, that everything which goes on in their interior can be distinctly seen. Yet there is considerable difference of opinion amongst observers as to their internal structure. It is admitted on all hands that they have a mouth, or aperture, for the admission of food; and in general a second aperture for the rejection of that which has to be cast out: and that food is conveyed into the mouth by the action of the *cilia* which surround it. But there is considerable doubt, whether it then passes into a regular intestinal tube, from which a series of little bags or stomachs open off; or whether it floats loosely in the general cavity of the body. The former is the view adopted by the celebrated Prussian naturalist, Ehrenberg, who has devoted several years to the study of animalcules; and who has on this account named the class POLYGASTRICA, or *many-stomached* Animalcules. The latter is the doctrine more generally entertained; and the question still remains to be decided.

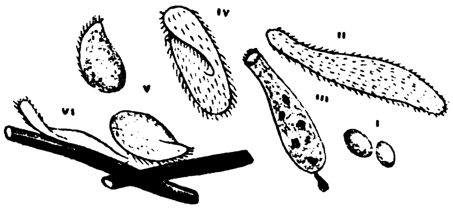


FIG. 79.—INFUSORY ANIMALCULES.
I. Monads; II. Trachelis anas. III. Enchelis, discharging fæcal matter; IV. Paramœcium; V. Kolpoda; VI. Trachelis fasciolaris.

137. These animalcules afford objects of never-ending interest to the microscopic inquirer. The variety of their forms, the rapidity of their movements, (which are accomplished by the action of their *cilia*,) their vast numbers, their quickness of multiplication, and the facility with which they may be studied, (for there is not a ditch, a stagnant pool, or a vessel of water in which organic matter has remained for a few days, that does not contain some of them,) concur to excite and to keep up the atten-

tion of all, who have even but an ordinary share of curiosity regarding the wonders of nature.

138. We thus conclude our general survey of the Animal Kingdom; which, it is hoped, will be found to answer the purpose for which it was designed, that of giving such an amount of preparatory knowledge respecting the different forms of animal structure, as may enable even the beginner to comprehend all that will hereafter be stated of their physiological actions. At any rate, even this brief and imperfect sketch will have probably served to extend the reader's acquaintance with the almost endless variety of tribes with which our globe is peopled; whilst it leads him, at the same time, to the perception of the Unity of that Design by which they were all formed at first, and by which the various parts they were destined to perform in the grand and harmonious concert of Nature were assigned to them. These parts they have continued to perform, without jarring or discordance; every class having its own operations to effect, its own destination to fulfil, and all being so connected together, that none could fail in its operation, without disturbing the whole. Who but an Almighty and All-wise Creator could have effected this; and who but an All-beneficent Father could have so arranged it, as to produce that universal happiness and enjoyment which we daily see, wherever the evil tendencies of Man have not interfered?

CHAPTER III.

NATURE AND SOURCES OF ANIMAL FOOD.

139. Before we examine the nature of the process by which the food of animals is prepared for absorption into their bodies, it will be desirable to consider the characters of the aliment itself, and the purposes to which it is to be applied. Strictly speaking, the term *aliment* may be applied to all those substances, which, when introduced into the living body, contribute to its growth, or to the repair of the losses which it is continually sustaining. Thus, water and air may be called aliments. But, in general, the term is used in a less extensive sense, being confined to those materials which are absorbed and applied to the purposes of nutrition only after undergoing the process of digestion: and in this sense it will be here employed. Aliments are not less necessary to the support of life than the air which we breathe, or than the water which our bodies are continually absorbing, either from the fluid we drink or from the vapour of the atmosphere. When animals are deprived of food, we see their bodies progressively diminishing in bulk, their strength decreases, and death at last takes place, after sufferings more or less prolonged.

140. The demand of the body for food is made known by a peculiar sensation, which has its seat in the stomach, namely, *hunger*. It is increased by exercise, by the stimulating influence of a moderately-cold temperature, and by the action of certain substances (which are known in medicine under the name of *tonics*) upon the stomach and general system. On the contrary, everything which tends to retard the operations of life, such as bodily and mental inactivity, sleep, &c., tend also to render the demand for food less imperious. Animals which pass

the winter in a state of torpidity, require no food during the whole continuance of their lethargy; and cold-blooded animals, particularly Reptiles, can sustain a very prolonged abstinence; especially when the general activity of their functions is kept down by a low temperature. But warm-blooded animals, whose vital operations are performed with activity and energy, require a much more constant supply of nourishment, and consequently perish sooner when deprived of it. This is the case with Man and the Mammalia, and still more with Birds, whose temperature is higher, and whose movements are more active and energetic. It is also more the case with young animals than with adults; since in the former the changes in the tissues are taking place, in consequence of the increase they are undergoing, with much more rapidity than they are in the latter, the bulk of whose bodies remains stationary. Hence, if children, young persons, and adults, be shut up together, and deprived of food, the youngest will usually perish first, and the adults will survive the longest. The Italian poet Dante has given a terrible picture of such an occurrence, in his history of the imprisonment of Count Ugolino and his children.

141. The difference in the demand for food between the young growing animal and that which has arrived at maturity is very remarkable in the case of Insects. There are no animals more voracious than the larva or caterpillar; and there are none that can sustain abstinence, with little diminution of their activity, better than the imago or perfect insect. The larvæ of the Flesh-fly, produced from the eggs laid in carrion, are said to increase in weight 200 times in the course of 24 hours; and their voracity is so great as to have caused Linnæus to assert, that three individuals and their immediate progeny (each female giving birth to at least 20,000 young, and a few days sufficing for the production of a third generation) would devour the carcase of a horse with greater celerity than a lion. The larva of the Silk-worm weighs, when hatched, about 1-100th of a grain; previously to its first metamorphosis it increases to 95 grains, or 9,500 times its original weight. The comparative weight of the full-grown caterpillar of the Goat-moth to that of the young one

just crept out of the egg, is said to be as 72,000 to 1. For this enormous increase a very constant supply of material is necessary, and many larvæ perish if left unsupplied with food for a single day. On the other hand, a black beetle (Melasoma) has been known to live seven months, pinned down to a board; and another beetle (Scarabæus) has been kept three years without food,—and this without manifesting any inconvenience or loss of activity. There are many perfect insects, which never eat after their last change, but die as soon as they have performed their part in the propagation of the race.

142. The nature of the food of animals is as various as the conformation of their different tribes. It always consists, however, of substances that have previously undergone organisation. There are some apparent exceptions to this, in the case of animals which seem to derive their support, in part at least, from mineral matter. Thus, the *Spatangus* (an animal allied to the Sea-urchin, §. 128) fills its stomach with sand; but it really derives its nourishment from the minute animals which this contains. The Earth-worm and some kinds of beetles are known to swallow earth; but only to obtain from it the remains of vegetable matter that are mixed with it. By some races of Man, too, what seems to be mineral matter is mixed with other articles of food, and is said to be nutritious; this may be beneficial, in part, by giving bulk to the aliment, and thus exciting the action of the stomach (§. 205); but it has been found, in one case at least, that the supposed earth consists of the remains of animalcules, and contains no inconsiderable portion of organic matter.

143. Gold-fish have been known to live and thrive in small vessels of water for two or three years, and have been said even to increase in weight, without any perceptible nutriment; and have hence been supposed to live on water and air alone. But, if they be not fed in any other way, it is requisite that the water they inhabit should be frequently changed; and as all spring and river-water, and even rain-water collected in a cistern that is in the least foul, contains a small quantity of organic matter, a sufficient source of their nutrition may be assigned, without

our having recourse to such an idea. In order to prove that no other nourishment than air and water is required for them, the fish ought to be carefully kept in *distilled* water; and this should be changed so frequently, as not to permit the production of any vegetation in it. For even ordinary water, exposed for some time to the air, will be found to contain some of the simplest kinds of cellular plants,—*these* requiring nothing more than those two elements for their support; and this growth will be more rapid, when the excretions of the fish, small though they may be in amount, give a certain degree of foulness to the water, which acts as a manure to the vegetation. Moreover it is to be remembered that Fishes, being cold-blooded animals, naturally require a comparatively small supply of nourishment; and it is said that some of them, as the perch, ordinarily take food but once a fortnight. These remarks are here introduced, to show the necessity for extreme caution, in drawing what may even seem to be necessary inferences from facts, about which there would not appear to be a possibility of doubt or mistake.

144. Adopting, then, as a general principle, that all animals require, as food, substances which have already formed a part of some organised body—either vegetable or animal—the first division of aliments is naturally into those which are derived from the two kingdoms respectively. Wherever Plants exist, we find Animals adapted to make use of the nutritious products which they furnish, and to restrain their luxuriance within due limits. Thus among the Mammalia, the Dugong (an animal having the general form and structure of the whale, but adapted to a vegetable diet) browses upon the sea-weeds that grow beneath the surface of the tropical ocean; the Hippopotamus roots up with his tusks the plants growing in the beds of the African rivers, and fills his huge paunch, not only with these, but with the decaying vegetable matter which he finds in the same situation; the Antelopes, Deer, Oxen, and other Ruminants, crop the herbage of the plains and meadows; the Giraffe is enabled, by his enormous height, to feed upon the tender shoots which are above the reach of ordinary quadrupeds; the Sloths, living entirely in trees, and hanging from their branches, strip them

completely of their leaves; the Squirrels extract the kernels of the hard nuts and seeds; the Monkeys devour the soft pulpy fruits; the Boar grubs up the roots and seeds buried under the soil; the Reindeer subsists during a large part of the year upon a lichen that grows beneath the snow, and the Chamois finds a sufficient supply in the scanty vegetation of Alpine heights. Not less is this the case among Birds; but in the classes of Reptiles and Fishes, the number of vegetable-feeders, and consequently the variety of their food, is much less.

145. Among Insects, a very large proportion derive their food entirely from plants, and many from particular tribes of plants only; so that, if from any cause these should fail, the race may for a time disappear. There is probably not a species of plant which does not furnish nutriment for one or more tribes of insects, either in their larva state or perfect condition, and in this manner it is prevented from multiplying to the exclusion of others. Thus on the oak, no less than two hundred kinds of caterpillars have been estimated to feed; and the nettle, which scarcely any beast will touch, supports fifty different species of insects,—but for which check it would speedily annihilate all the plants in its neighbourhood. The habits and economy of the different races existing on the same plant are as various as their structure. Some feed only upon the outside of the leaves; some upon the internal tissue; others upon the flowers or on the fruit; a few will eat nothing but the bark, while many derive their nourishment only from the woody substance of the trunk.

146. The excessive multiplication of certain tribes of Insects has sometimes had the effect of devastating an entire country. Thus the "plague of locusts" is not unfrequently repeated in tropical countries, and is dreaded by the inhabitants even more than an earthquake. These insects are of such extreme voracity, that no green thing escapes them; and when their numbers are so increased, that they fly in masses which look like dark clouds, and cover the ground where they alight for miles together, it may be easily conceived that the devastation they create must produce incalculable injury. The north of Africa and the west of Asia are the countries most infested by these pests. It is

related by Augustin, that a plague, induced partly by the famine they had created, and partly by the stench occasioned by their dead bodies, carried off 800,000 inhabitants from the kingdom of Numidia and the adjacent parts. They occasionally attack the south of Europe. It is recorded that Italy was devastated by them in the year 591; and that a prodigious number both of men and beasts perished from similar causes,—no less than 30,000 persons in the kingdom of Venice alone. These tremendous swarms usually advance towards the sea; and being there checked, and having completely exhausted the country behind them, they themselves die of famine, or are blown into the sea by a gale. In 1784 and 1797, they devastated Southern Africa; and it is stated by Mr. Barrow (in his Travels in that country) that they covered a surface of 2,000 square miles; and that, when cast into the sea by a strong wind from the north-east, and washed upon the beach, they formed a line fifty miles long, and produced a barrier along the coast three or four feet high; and that, when the wind again changed, the stench created by the putrefaction of their bodies was perceived at a distance of 150 miles inland. A similar event occurred in the Barbary States in 1799, and was followed, as in the other cases, by a plague.

147. We have occasionally an example of similar devastation in our own country, though on a smaller scale. Thus, a few years ago, the turnip-crops of some parts of England were almost entirely destroyed by the larvæ of an insect called the turnip-fly. The parent insects were seen buzzing over the fields, and depositing their eggs in the plants, which they do not themselves employ as food; and in a few days, all the soft portions of the leaves were destroyed, and nothing but the skeletons and stalks were left. Some kinds of timber occasionally suffer to no less an extent from the devastations of insects whose operations are confined to the wood, and do not manifest themselves externally, until the tree is seen to languish and at last to die. The pine-forests of the Hartz mountains in Germany, have been several times almost destroyed by the ravages of a single species of beetle, less than a quarter of an inch in

length. The eggs are deposited beneath the bark; and the larvæ, when hatched, devour the sap, wood, and inner bark (the parts most concerned in the functions of vegetation) in their neighbourhood. It was estimated that, in the year 1783, a million and a half of pines were destroyed by this insect in the Hartz alone; and other forests in Germany were suffering at the same time. The wonder is increased when it is stated that as many as 80,000 larvæ are sometimes found on a single tree.

148. But every class in the Animal Kingdom has its carnivorous tribes, which are adapted to restrain the too rapid increase of the vegetable-feeders (by which a scarcity of their food would soon be created), or to remove from the earth the decomposing bodies that might otherwise be a source of disease or annoyance. The herbivorous races are for the most part very prolific, and they may very rapidly increase to such an extent as to produce an absolute famine, if they be not kept in check by the races appointed to restrain their multiplication. Thus, the myriads of insects which find their subsistence in our forest trees, if allowed to increase without restraint, would soon destroy the life that supports them, and must then all perish together; but another tribe (that of the insectivorous birds, as the woodpecker) is adapted to derive its subsistence from them, and thus to keep their numbers within salutary bounds. Their occasional multiplication to the enormous extent mentioned in the preceding paragraphs, is probably due in general to the absence of the races that should keep them in check. This may occur from accidental causes, or may be produced by the interference of Man. Thus, a set of ignorant farmers have imagined that a neighbouring rookery was injurious to them, because they saw the rooks hovering over the newly-sown corn-fields, and seeming to pick the grains out of the ground; and having extirpated the rookery, they have found in the course of a year or two, that they have done themselves an immense injury,—the roots of their corn and grasses being devoured by the grubs of cockchafers and other insects, the multiplication of which was before prevented by the rooks, whose natural food they are.

149. On the other hand, by an intelligent application of this

principle, the excessive multiplication of insects has been prevented where it had already commenced. Thus, no means of extirpating the larvæ of the turnip-fly was found so successful, as turning into the fields a number of ducks, which quickly removed them from the plants. And in the island of Mauritius, the increase of locusts, which had been accidentally introduced there, and which were becoming quite a pest, was checked by the introduction from India of a species of bird, the grakle, which feeds upon them.

150. Of the carnivorous tribes themselves, however, the increase might be so great as to destroy all the sources of *their* food, were it not that they are kept in check by others, larger and more powerful than themselves, which, not being prolific, are not likely ever to gain too great a power. Thus, among birds, the eagles, falcons, and hawks rear only two or three young every year, whilst many of the smaller birds produce and bring up four or five times that number. The following is a curious instance of the system of checks and counterchecks, by which the "balance of power" is maintained amongst the different races. A particular species of moth has the fir-cone assigned to it for the deposition of its eggs, the young caterpillars, coming out of the shell, consume the cone and superfluous seed; but, lest the destruction should be too great, another insect of the ichneumon kind lays its eggs in the caterpillar, inserting its long tail in the openings of the cone, until it touches the included insect,—its own body being too large to enter. Thus it fixes upon the caterpillar its minute egg, which, when hatched, destroys it.

151. The peculiarity of the agency of insects, in the economy of nature, consists in their power of very rapid multiplication, in order to accomplish a certain object, and then in their as rapidly dying off. In this respect they resemble the Fungi among plants; and the observations elsewhere made in regard to these (VEGET. PHYS. §. 64), may be referred to as illustrating the character of their operations.

152. An attempt has been made to show that herbivorous animals are more dependent upon a constant supply of food than carnivorous species; and that domesticated animals support ab-

stinence less easily than wild ones. But these statements, though true in general, do not by any means constantly hold good. It would probably be more correct to state, that, in proportion to the facility with which each species obtains its food, will be its inability to live long without it. Thus, among the larvæ of insects, those that feed upon vegetables or dead animal matter (in the neighbourhood of which their eggs are usually deposited by the parent) speedily die if placed out of reach of their aliment; whilst those that lie in wait for living prey, the supply of which is uncertain, are able to endure a protracted abstinence, even to the extent of ten weeks, without injury. Again, the carnivorous birds and mammalia are generally able to exist for some time without food; their natural habits leading them to glut themselves upon the carcase of the animal they have destroyed, in such a manner as to prevent them from requiring any new supply for some time. Thus the Wild Cat has been kept twenty days without food; the Dog has lived for thirty-six days in the same circumstances, and the Eagle for a similar period. But some herbivorous animals, such as the Camel and the Antelope, whose habits are such as to keep them out of the reach of food for several days together, are able to endure a similar abstinence; whilst among the insectivorous Mammalia, which naturally take food often, and but little at a time, the power of abstinence is much less,—the Mole, for instance, perishing in confinement, if not fed once a day, or even more frequently.

153. We have next to consider the different substances used as food, in regard to their chemical composition, and to inquire for what purposes in the nutrition of the body they are respectively destined. The *Vegetable* tissues, as explained elsewhere (VEGET. PHYS. Chap. VI.) are made up of the *three* ingredients, oxygen, hydrogen, and carbon, alone; and the proportions of these ingredients are very nearly the same as those which exist in starch, gum, and sugar; into which, indeed, they may be converted by a simple chemical process. Hence all alimentary substances of this kind may be included in a group, to which we may give the name of *saccharine* (sugary). But in many vegetable substances used as food, there is a considerable quantity of

oily matter, stored up in cells; and the same kind of matter constitutes the principal part of the fat of animals. Of these oily and fatty matters, also, the chemical elements, oxygen, hydrogen, and carbon, are the only ingredients; but they are combined in proportions different from the last, the two latter predominating considerably. Hence they constitute another group of alimentary materials; to which the term *oleaginous* may be given. Lastly, most Vegetables contain, in greater or less amount, certain compounds, which consist of the *four* elements, oxygen, hydrogen, carbon, and nitrogen, of which the *animal* tissues are composed. These compounds do not form part of the vegetable *tissues*, but are laid up in their cavities; they exist most largely in the corn-grains, and also in the seeds of the pea and bean tribe; but there are few substances used as food by animals, that do not contain them in some small amount. The *gluten* of wheat, the *legumen* of peas, and other vegetable substances of this kind, together with the flesh of animals—the composition of which is identical with theirs—are united into a third group, to which the name *albuminous* is given. We cannot properly include in this group, however, the *gelatinous* portions of the animal tissues, which exist largely in gristle, bone, the skin, and other parts; because gelatin (the substance that forms glue) though it agrees with albumen in being made up of the *four* ingredients just named, differs from it extremely in the proportions of those elements (§.21); so that, although there is good reason to believe that gelatin may be formed out of albumen, it does not seem that albumen and fibrin can be formed out of gelatin. Hence we must consider the gelatinous compounds separately.

154. Of these four groups, the last two are distinguished as including all the *azotized* compounds, or substances that contain *azote* or nitrogen; whilst the first two are spoken of as *non-azotized*, being destitute of this element. The distinction is a very important one; and must be kept steadily in view, in considering the ultimate destination of each kind of food. The azotized compounds alone can be applied without change to the nutrition and re-formation of the animal tissues. The non-azotized substances must be destined, either to undergo important

changes within the animal body, or to be thrown off from it again, without ever actually forming part of its organised structure. In reference to this statement, the distinction between the *organisation* of a substance, and the simple *deposition* of it in the midst of an organised tissue, must not be lost sight of; thus the mineral particles which enter into the composition of the vegetable tissues (VEGET. PHYS. §. 170) retain their crystalline character, and may be separated unchanged from the organic matter with which they are associated. Again, it has been pointed out that the oily matter of fat cannot be said to be part of the organised structure, being merely stored up in cells, from which it may be removed without any change in its own nature (§. 44). Hence the oily matter taken in as part of the food, (whether it be derived from animals or plants,) and deposited in fat, cannot be regarded as ever becoming organised.

155. Now in regard to the non-azotized, or the *saccharine* and *oleaginous* groups of alimentary substances, it appears to be an established fact, that none of the higher animals can be permanently supported upon them alone. Thus, dogs that have been fed on sugar and starch only, do not survive long; and it is evident, before their death, that their tissues are gradually undergoing decay. It has been thought that such results might be partly explained upon the fact, that animals fed upon one simple substance soon become disgusted with it, and will even refuse it altogether; but the experiments have been repeated with a combination of various non-azotised substances, and the same result has occurred. Still it would appear too much to say, as some have done, that these substances do not contribute, in any degree, to the nutrition of the animal tissues; since there is evidence that, even in the highest animals, a production of albumen takes place in the chyle, at the expense of fatty matter (§. 222); and there are several facts which seem to show that animals may, for a time at least, thrive upon saccharine substances only. Thus gum forms an important article of diet in Arabia and Senegal, where it is produced largely by trees of the Acacia tribe, and is collected for the supply of Europe. Those who gather it live for a time almost entirely upon it; and six

ounces have proved sufficient to support an adult for twenty-four hours. It is on record, that a caravan crossing the desert, preserved themselves from famine—their provisions being exhausted—by eating the gum arabic which formed part of the merchandise they were transporting. In like manner, the Negroes employed in the cultivation of sugar, are in the habit of taking large quantities of cane-juice during the crop season; and it seems not only to make them plump, but to improve their vigour. Again, the potatoes which form the principal food of the Irish peasantry, and the rice on which some of the Hindoo races live almost exclusively, consist almost entirely of starchy matter. But a still more important fact is that which is familiar to those who have experimented on the habits and economy of Bees;—namely, that these insects will live for almost any length of time, confined to their hives, and forming wax and honey, when fed with pure syrup alone. It is possible that the peculiar energy of their respiration enables them to combine the azote of the air, with their non-azotized food, in a degree sufficient for their wants; which certainly *cannot* be done *for a continuance* by any of the higher animals.

156. The question whether substances of the *saccharine* group can be converted, in the animal body, into *oleaginous* compounds, is one at present under discussion amongst chemists. There would seem many arguments in favour of this view, which cannot easily be explained away. Of this kind are the formation of wax (a fatty matter) by bees from sugar only; the fattening of the negroes when they drink largely of the saccharine cane-juice; and the discharge of a large quantity of fatty matter (butter) in the milk of a cow that is fed upon starchy matters. If we admit that such may be the case, we are enabled to explain the destination of the alimentary substances of the saccharine group better than we can otherwise do; for they cannot be recognised *as such* either in the chyle or blood; but a considerable quantity of fatty matter exists in both, to the formation of which they seem to contribute.

157. But if these non-azotized compounds, which exist so largely in the food of herbivorous animals, are not destined to

form part (in any considerable degree at least) of their tissues, the question again arises,—what becomes of them? It is not enough to say that they are deposited as fat; since it is only when a large quantity of them is taken in, that there is any increase in the quantity of fat already in the body. We shall hereafter see that they are used up in the process of respiration, one great object of which is, to produce a certain amount of heat, sufficient to keep up the temperature of the body, in warm-blooded animals, to a high standard. We might almost say with truth, that a great part of the oleaginous and saccharine principles is *burned* within the body, for this purpose. The process will be hereafter considered more in detail (Chap. VI.); and at present we need only stop to remark upon the adaptation between the food provided for animals in different climates, and the amount of heat which it is necessary for them to produce. Thus the bears, and seals, and whales, from which the Esquimaux and the Greenlander derive their support, have an enormous quantity of fat in their massive bodies: this fat is as much esteemed as an article of food among these people, as it would be thought repulsive by the inhabitants of southern climates; and by the large quantity of it they consume, they are able to support the bitterness of an Arctic winter, without appearing to suffer more from the extreme cold, than do the residents in more temperate climes during *their* winter. On the other hand, the antelopes, deer, and wild cattle, which form a large proportion of the animal food of savage or half-cultivated nations inhabiting tropical regions, possess very little fat; and the comparatively small supply of carbon and hydrogen, of which the combustion is required to keep up the bodily temperature of the inhabitants of those regions, is derived from the *flesh* of these animals, in the manner that will be presently explained.

158. The application of the substances forming the *albuminous* group, to the support of the animal body, by affording the materials for the nutrition and re-formation of its tissues, needs little explanation. The proportions of the four ingredients of which they are all composed, are so nearly the same, that no essential difference appears to exist among them; and it is a matter of

little consequence, except as far as the gratification of the palate is concerned, whether we feed upon the flesh of animals (fibrin), upon the white of egg (albumen), the curd of milk (casein), the grain of wheat (gluten), or the seed of the pea (legumin). All these substances are reduced in the stomach to the form of *albumen*; which resembles the *gum* of plants in being the raw material, as it were, out of which the various fabrics of the body are constructed. But the rule holds good, with regard to these also, that by being made to feed constantly on the same substance,—boiled white of egg for instance, or meat deprived of the principle that gives it flavour,—an animal may be effectually starved; its disgust at the food being such, that even if it be swallowed, it is not digested. It is very interesting to remark that, in the only instance in which Nature has provided a *single* article of food for the support of the animal body, she has mingled articles from all the three preceding groups. This is the case in *milk;* which contains a considerable quantity of an albuminous substance, *casein*, which forms its curd; a good deal of *oily* matter, the butter; and no inconsiderable amount of *sugar*, which is dissolved in the whey. The proportions of these vary in different Mammalia; and they depend in part upon the nature of the food supplied to the animal that forms the milk; but the substances are thus combined in every instance.

159. Although the greater part of the organised tissue of animals is formed at the expense of the albumen and fibrin of their blood, yet many of them also contain a large quantity of *gelatin*. It seems certain that this gelatin may be produced out of fibrin and albumen; since in animals that are supported on these alone, the nutrition of the gelatinous tissues does not seem to be impaired. But it also appears that gelatin taken in as food may be applied to this purpose; for ordinary experience shows that benefit is derived from jelly, soup, broth, &c.; peculiarly by persons who have been suffering under exhausting diseases, such as fevers. But it also appears certain, that it cannot be applied to the nutrition of the albuminous tissues. Some important experiments have been recently made in Paris on this subject; with a view of determining how far the soup made from

crushed bones, which constituted a principal article of diet in the hospitals of Paris, was adequate for the support of the patients. The result of these has been quite confirmatory of previous conclusions,—namely, that gelatin may be advantageously mixed with albumen, fibrin, gluten, &c., and those other ingredients which exist in meat-soup and bread; but that, when taken alone, it has little more power of sustaining life than sugar or starch possesses; and that, even when bread is united with the gelatin-soup, it does not give it the requisite power of nutrition.

160. It has been already stated (§. 53, 54) that all the living tissues of the body are continually undergoing a sort of death and decay; and that they do this the more rapidly, in proportion as they are called upon for the discharge of their functions. This is, consequently, the chief source of the constant demand for aliment, capable of replacing that which has been lost. Even in young actively-growing animals, the quantity of aliment required for the increase of their bodies, constitutes but a very small proportion of that which is taken in; of the remainder, a part is at once rejected as indigestible; and the rest is appropriated to the repair of the *waste* which is continually going on. This waste is much greater in young animals than in adults; for all their vital processes are more actively and energetically performed; their movements are quicker in proportion to their size; and injuries are more speedily repaired. Now of this waste, the chief part is carried out of the body by the various processes of excretion; and among these, the *respiration*, by which a large quantity of carbon and hydrogen is carried off in the form of carbonic acid and water, is of the most constant importance, on account of the heat which it thus enables the animal body to maintain. This temperature, in Carnivorous animals, appears to be sufficiently kept up by the combustion of the carbon and hydrogen, set free by the decay (or metamorphosis, as it may be termed) of their tissues; but this combustion goes on with much more rapidity, in consequence of their almost unceasing activity, than it does in the Herbivorous animals, which lead comparatively inactive lives. Every one who has visited a menagerie must have noticed the

continual restlessness of the Tigers, Leopards, Hyænas, &c., which keep pacing from one end of their narrow cages to the other; and it would seem as if this restlessness were a natural instinct, impelling them to use muscular exertion sufficient for the metamorphosis of an adequate amount of tissue, that enough carbon and hydrogen may be set free for the support of the respiratory process. And we see a corresponding activity in the human hunters of the swift-footed antelope and agile deer, which answers a similar purpose; and which is remarkably contrasted with the stupid inertness of the inhabitants of the frigid zone, which is only occasionally interrupted by the necessity of securing the supplies of food afforded by the massive tenants of their seas.

161. The nutrition of the Carnivorous races may, then, be thus described. The bodies of the animals upon which they feed contain flesh, fat, &c., in nearly the same proportion as their own; and all, or nearly all, the aliment they consume, goes to supply the waste in the fabric of their own bodies, being converted into its various forms of tissue. After having remained in this condition for a certain time, varying according to the use that is made of them, these tissues undergo another metamorphosis, which ends in restoring them to the condition of inorganic matter; and thus give back to the mineral world the materials which were drawn from it by plants. Of these materials, part are burned off, as it were, within the body, by union with the oxygen of the air, taken in through the lungs; and they are discharged from these organs in the form of carbonic acid and water: the remainder are carried off in the liquid form by other channels. Hence we may briefly express the destination of their food in the following manner:—

$$\left.\begin{array}{l}\text{Food consisting of}\\ \text{albumen, fibrin,}\\ \text{and other azo-}\\ \text{tised compounds}\end{array}\right\}\begin{array}{c}\text{converted}\\ \text{into}\end{array}\left\{\begin{array}{c}\text{Living}\\ \text{organised}\\ \text{tissue}\end{array}\right\}\begin{array}{c}\text{and this}\\ \text{metamorphosed}\\ \text{into}\end{array}\left\{\begin{array}{l}\left\{\begin{array}{l}\text{Carbonic acid and}\\ \text{water, thrown off}\\ \text{by respiration.}\end{array}\right.\\ \left\{\begin{array}{l}\text{Urea and biliary}\\ \text{matter, \&c.,}\\ \text{thrown off by}\\ \text{other excretions.}\end{array}\right.\end{array}\right.$$

162. But in regard to the Herbivorous animals, the case is different. They perspire much more abundantly, and their

temperature is thus continually kept down (Chap. VIII.). They consequently require a more active combustion, to develope sufficient bodily heat; and the materials for this are supplied, as we have seen, by the non-azotised portions of their food, rather than by the metamorphosis of their own tissues, which takes place with much less rapidity than in the carnivorous tribes. Hence we may thus express the destination of this part of their food; that of the azotised matter, here much smaller in amount, will be the same as in the preceding case.

Starch, oil, and other non-azotised compounds	partly converted into	Fatty and other animal tissues	but chiefly thrown off directly as	Carbonic acid and water, disengaged by the respiratory process.

The proportion of the food deposited as fat, will depend in part upon the surplus which remains, after the necessary supply of materials has been afforded to the respiratory process. Hence, the same quantity of food being taken, the quantity of fat will be increased by causes that check the perspiration, and otherwise prevent the temperature of the body from being lowered, so that there is need of less combustion within the body to keep up its heat. This is consistent with the teachings of experience respecting the fattening of cattle; for it is well known that this may be accomplished much sooner, if the animals are shut up in a warm dwelling and are covered with cloths, than if they are freely exposed in the open air.

163. Now the condition of Man may be regarded as intermediate between these two extremes. The construction of his digestive apparatus, as well as his own instinctive propensities, point to a mixed diet as that which is best suited to his wants. It does not appear that a diet composed of *ordinary* vegetables only, is favourable to the full development of either his bodily or his mental powers; but this cannot be said in regard to a diet of which *bread* is the chief ingredient, since the gluten it contains appears to be as well adapted for the nutrition of the animal tissues, as does the flesh of animals. On the other hand, a diet composed of animal flesh alone is the least economical that can be conceived; for, since the greatest demand for food is created in him (taking a man of average habits in regard to activity and

the climate he inhabits), by the necessity for a supply of carbon and hydrogen to support his respiration, this want may be most advantageously fulfilled by the employment of a certain quantity of non-azotised food, in which these ingredients predominate. Thus it has been calculated, that, since fifteen pounds of flesh contain no more carbon than four pounds of starch, a savage with one animal and an equal weight of starch, could support life for the same length of time, during which another restricted to animal food would require five such animals, in order to procure the carbon necessary for respiration. Hence we see the immense advantage as to economy of food, which a fixed agricultural population possesses over the wandering tribes of hunters which still people a large part both of the old and new continents.

164. The mixture of the azotised and non-azotised compounds (gluten and starch), that exists in wheat-flour, seems to be just that which is most useful to Man; and hence we see the explanation of the fact, that, from very early ages, bread has been regarded as the "staff of life." In regard to the nutritious properties of different articles of vegetable food, these may be generally measured by the proportion of azote they contain, which is in almost every instance less than that which exists in good wheat-flour. But it must not be forgotten that, owing to the varieties of constitution which have been pointed out among different animals, the power of particular substances to nourish Man and Cattle is not the same,—the latter requiring a larger proportion of the saccharine and oleaginous compounds, than is beneficial to him,—especially when it is an object to cause a large quantity of fatty matter to be deposited in their tissues, or to be excreted in milk. Thus potatoes are found to increase the proportion of butter in the milk of a cow that feeds upon them; their starch being probably converted into fatty matter. It has been also shown by recent experiments, that the proportion of butter in the milk of a cow allowed to feed during the day in a pasture, and shut up at night in a warm stall, was much greater in the morning milk than in the evening,—the former containing 5·6 parts of butter in 100, and the latter only 3·7 parts. This was evidently due to the diminished demand for the materials

for respiration during the night, when the body was at rest and the skin kept warm. The experiment was then tried, of keeping the cow in a shed during the day, and feeding her with the same grass; and the proportion of butter in her evening milk then rose to 5·1 parts in 100. But this plan diminished the proportion of casein or cheesy matter in the milk, which was increased again by allowing the cow to pasture in the open field. Hence it appears that stall-feeding is most favourable to the production of butter, and pasturing to that of cheese.

165. These principles should be kept in view in regulating the diet of individuals, especially in certain disordered states of the constitution, which require to be treated by strict attention to diet. Thus there are some persons who have a remarkable tendency to the deposition of fat; and others in whom there is a morbid (or diseased) production of sugar in the body, which is carried off by the urine. In these cases, the diet should be so regulated as to contain the least possible quantity of the saccharine or oleaginous principles; the food being made to consist entirely of animal flesh, with a very small quantity of bread,—or still better, with bread from which the greater part of the starch has been removed. On the other hand, there is a state of the system, known as that in which gout and gravel are liable to occur, in which there seems to be an excess of azotised matter; and the diet of such persons should be so regulated, that very little or no animal flesh should be employed as food, the aliment being made to consist almost exclusively of farinaceous (starchy) substances, such as rice, potatoes, &c.

166. Besides these substances, there are certain mineral ingredients, which may be said to constitute a part of the food of animals; being necessary to *their* support, in the same manner as other mineral substances are necessary to the support of plants (VEGET. PHYS., Chap. VI.). Of this kind are common salt, and also phosphorus, sulphur, and lime, either in combination or separate. The uses of *Salt* are very numerous and important. It consists of two substances of opposite qualities, muriatic acid and soda; and the former is the essential ingredient in the gastric juice (§. 204); whilst the latter performs a very important part

in the production of bile. *Phosphorus* is chiefly required to be united with fatty matter, to serve as the material of the nervous tissue; and to be combined with oxygen and lime, to form the bone-earth, by which the bone is consolidated. *Sulphur* exists in small quantities in several animal tissues; but its part is by no means so important as that performed by phosphorus. *Lime* is required for the consolidation of the bones, and for the production of the shells and other hard parts that form the skeletons of the Invertebrata. Of the limestone rocks, of which a great part of the crust of our globe is composed, a very large proportion is made up of the remains of animals that formerly existed in the ocean. Thus some are almost entirely made up of masses of coral, others of beds of shells, and others of the coverings of animalcules of extreme minuteness. To these ingredients we may also add *iron*, which is a very important element in the red blood of Vertebrated animals.

167. These substances are contained, more or less abundantly, in most articles generally used as food; and where they are deficient, the animal suffers in consequence, if they are not supplied in any other way. Thus common *salt* exists, in no inconsiderable quantity, in the flesh and fluids of animals, in the milk, and in the egg: it is not so abundant, however, in plants; and the deficiency is usually supplied to herbivorous animals, by some other means. Thus salt is purposely mingled with the food of domesticated animals; and in most parts of the world inhabited by wild cattle, there are spots where it exists in the soil, and to which they resort to obtain it. Such are the "buffalo-licks" of North America. *Phosphorus* exists also in the yolk and white of the egg, and in milk,—the substances on which the young animal subsists during the period of its most rapid growth; and it abounds not only in many animal substances used as food, but also (in the state of phosphate of lime or bone-earth) in the seeds of many plants, especially the grasses. So abundant is this in oats, that the horse is subject to an earthy concretion in its intestinal canal; in which phosphorus is a principal ingredient. In smaller quantities it is found in the ashes of almost every plant. When flesh, bread, fruit, and husks of grain, are used as the chief

articles of food, more phosphorus is taken into the body than it requires; and the excess has to be carried out in the excretions. *Sulphur* is derived alike from vegetable and animal substances. It exists in flesh, eggs, and milk; also in the azotised compounds of plants; and (in the form of sulphate of lime) in most of the river and spring water that we drink. *Iron* is found in the yolk of egg, and in milk, as well as in animal flesh; it also exists, in small quantities, in most vegetable substances used as food by man,—such as potatoes, cabbage, peas, cucumbers, mustard, &c.; and probably in most articles from which other animals derive their support.

168. *Lime* is one of the most universally diffused of all mineral bodies; for there are very few animal or vegetable substances in which it does not exist. It is most commonly taken in, among the higher animals, combined with phosphoric acid, so as to form bone-earth; and in this state it exists largely in the seeds of most grasses, especially in wheat-flour. If it were not for their deficiency in phosphate of lime, beans and peas would be more nutritious than wheaten-flour, the proportion of azotised matter they contain being much larger. A considerable quantity of lime exists, in the state of carbonate and sulphate, in all hard water. When an unusual demand exists for lime, however, for a particular purpose, an increased supply must be afforded. Thus a hen preparing to lay, is impelled by her instinct to eat chalk, mortar, or some other substance containing the carbonate of lime, which is required for the consolidation of the shell; and if this is withheld, the egg is soft, its covering being composed of animal matter alone, not consolidated by the deposit of earthy particles. The thickness of the shells of the aquatic Mollusca depends greatly upon the quantity of lime in the surrounding water. Those which inhabit the sea, find in its waters as much as they require; but those that dwell in fresh-water lakes, which contain but a small quantity of lime, form very thin shells; whilst, on the other hand, those that inhabit lakes in which, from peculiar local causes, the water is loaded with calcareous matter, form shells of remarkable thickness.

169. It is a very curious question, from what source the coral-forming Polypes have obtained the enormous quantities of

lime that have served to build up their gigantic structures. It seems probable that, in the parts of the globe where they now most abound, which are the seats of frequent volcanic action, there are springs whose waters contain a large quantity of carbonate of lime (as hot springs in the neighbourhood of volcanoes, such as the Geysers in Iceland usually do); and that these, emptying themselves beneath the sea, furnish the required supply. Thus the materials required by the coral animals are being continually supplied from the deep-seated rocks beneath. And there is further reason to believe, that a similar process formerly took place through a much wider portion of the surface of the globe, and that the waters of the sea were much more loaded with carbonate of lime; for in this way only can we account for the vast limestone beds, formed of successive growths of coral, which constitute a great part of our solid land, their thickness being many hundred feet, and in some places two or three thousand feet. We may reasonably suppose that, by the operations of these creatures, continued through many ages, the proportion of lime dissolved in the waters of the sea was gradually reduced, and at last brought down to its present amount; just in the same manner as the atmosphere seems to have been gradually purified from a large quantity of carbonic acid gas (which would have been fatal to warm-blooded animals), by the continued growth of those luxurious forests, which, having been buried beneath other deposits, have come down to us as coal. (See VEGET. PHYS., §. 298.)

170. The mode in which the Crustacea, whose calcareous shell is periodically thrown off (§. 107), are able to renew it with rapidity, is very curious. There is laid up in the walls of their stomachs a considerable supply of calcareous matter, in little concretions, which are commonly known as "crabs' eyes." When the shell is thrown off, this matter is taken up by the blood, and is thrown out from the surface, mingled with the animal matter of which the shell is composed. This hardens in a day or two, and the new covering is complete. The concretions in the stomach are then found to have disappeared; but they are gradually replaced, before the supply of lime they contain is again required.

CHAPTER IV.

DIGESTION AND ABSORPTION.

171. Having now considered the nature of the food of Animals, and the sources from which it is obtained, we have next to consider the process by which the aliment is received into their bodies and prepared to form a part of their own fabric. This process, termed *digestion*, is naturally divided, among the higher animals at least, into various stages. In the first place, there is the *prehension* or *laying hold* of the aliment, and its introduction into the mouth, or entrance to the digestive cavity. In the mouth it usually undergoes a preparation; which consists partly in its being cut, ground, or crushed, by mechanical action, into minute pieces; and partly in the working up of these pieces with a fluid that is poured into the mouth,—the saliva. These two processes are termed *mastication* and *insalivation;* similar processes are performed, in some animals, in a part of the digestive tube intermediate between the mouth and stomach, and even in the latter itself. The stomach is usually situated at some distance from the mouth, and is connected with a tube called the *œsophagus* or gullet; and the passage of the food into this, constituting the act of swallowing, is termed *deglutition.* The food, having arrived in the stomach, is acted upon by a peculiar fluid which it contains, and its alimentary portion is completely dissolved, so that a pulpy mass is formed, which is termed *chyme;* hence this process, which is the first stage of digestion properly so called, is termed *chymification*, or the manufacture of chyme. The chyme, which passes into the intestines, is further acted on by secretions that are poured into them; and the nutritious portion, or *chyle*, is separated from the matters that are to be thrown off: this process, which is the second stage of true digestion, is termed *chylification.* The rejected portions of the food, with

secretions poured into the alimentary canal, find their way out through the intestinal tube; and are voided at its second orifice by the act of *defecation*. And lastly, the nutritious chyle is taken up by vessels that are distributed upon the walls of the digestive cavity, and undergoes a gradual change by which it is converted into blood. These two processes are called *absorption* and *sanguification* (or manufacture of blood). Each of the foregoing stages will now be separately considered.

Prehension of Food.

172. The introduction of aliment within the entrance to the digestive cavity is accomplished in various methods in different animals. In the Mammalia in general, the aperture of whose mouth is guarded by fleshy lips, these, with the jaws and teeth, are the chief instruments of this operation. But in Man and the Monkey tribe (Fig. 80) the division of labour is carried further; the food being laid hold of by the anterior members, or hands, and by them carried to the mouth. Where the hand has the power of grasping, and especially

FIG. 80.—OUISTITI.

FIG. 81.—SQUIRREL.

where the thumb can be *opposed* to the fingers, the action of a single member is sufficient; but there are several animals which, like the Squirrel, use both limbs conjointly to hold their food, the extremity not having itself the power of grasping. The Ant-eaters, Woodpeckers, Chameleons, and other insect-eating animals, obtain their food by means of a long extensible tongue; this either serving to transfix the insect, or to glue it to the surface, which is covered with a viscid saliva. The Giraffe uses its long tongue to lay hold of the young shoots on which it browzes; and the Elephant employs its trunk, which is nothing else than a prolonged nose, for every kind of prehension (Fig. 82). Many of the Invertebrata are furnished with little appendages round their mouths, by which the food is conveyed into them; such are the *palpi* of Insects, of which a pair is attached to each jaw (Fig. 84); the *tentacula* of the Mollusca, which are sometimes extremely prolonged, as in

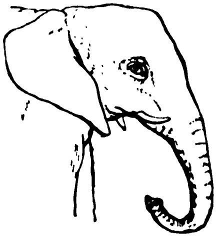


FIG. 82.—HEAD OF ELEPHANT.

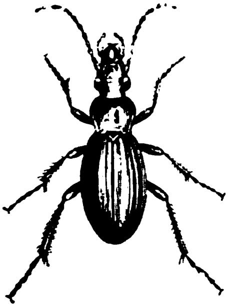


FIG. 83.—CARABUS.

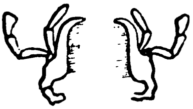


FIG. 84.—JAWS OF THE SAME INSECT.

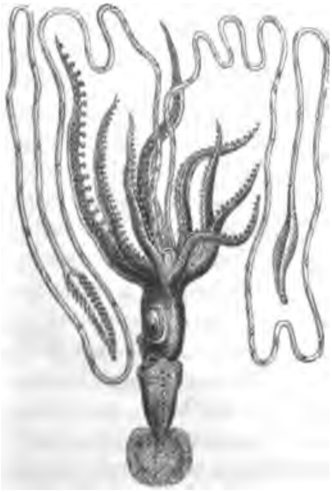


FIG. 85.—LOLIGOPSIS.

the cuttle-fish tribe (Fig. 85); and the similar organs of the polypes (Fig. 1).

FIG. 86.—CHIMPANZEE DRINKING.

173. The reception of fluids is accomplished in two ways. Sometimes the liquid is made to fall into the mouth, simply by its own weight; in other instances it is drawn or pumped up by this cavity,—either by the expansion of the chest, which causes a rush of air towards the lungs,—or by the movement of the tongue, which, being drawn back like a piston, produces the action of sucking. Some of the lower animals are destined to be entirely supported by liquids which they find in plants, or which they draw from the bodies of other animals on which they live as parasites. This is the case with many insects; and their mouth, instead of presenting the ordinary structure, is formed into a sort of tube or trunk, very much extended, through which the juices are drawn up according to the wants of the animal. Such a conformation exists in the butterfly and moth tribe, whose trunk, when not in use, is coiled up in a spiral beneath the head; as is shown in Fig. 87, representing the head of a Butterfly, *a*, of which the eye is seen at *c*, the base of the antennæ at *b*, the palpi at *e*, and the trunk at *d*. In some of the Fly tribe, the trunk attains a length several times greater than that of the body, as shown in Fig. 88, representing a dipterous (two-winged) insect from the Cape of Good Hope, which sucks the juices of a single kind of flower, the length of whose tube just equals that of its long proboscis.

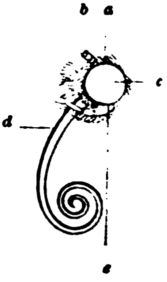


FIG. 87.—TRUNK OF A BUTTERFLY.

Mastication.

174. The act of *Mastication*, or the mechanical division of the alimentary matter, is effected in most of the higher animals, by *teeth*, which are implanted in the jaws. These are composed of a substance that bears a strong resemblance to bone in its texture and hardness; and are so fixed as to act against one another, with a cutting, crushing, or grinding power, according to the nature of the food on which they have to operate. The manner in which they are formed is worthy of note. In Man, who may be taken as a fair example, each tooth is developed in the interior of a little membranous sac, which is lodged in the thickness of the jaw-bone; as seen in the accompanying figure, which represents half the lower jaw of a very young infant, from which the outside has been removed. This sac, which is named the *dental capsule*, (*a*, Fig. 90,) is composed of two membranes, abundantly furnished with blood-vessels; and it encloses in its interior a little bud-like protuberance, *b*, in which ramify a great number of nervous filaments and minute vessels, *c*. The matter composing this little body, which is termed the *pulp*, is gradually converted into the *ivory* of the tooth, which

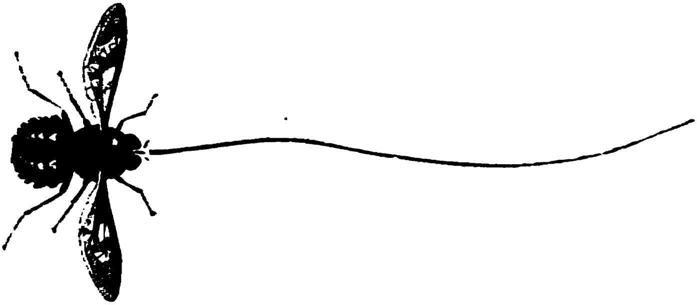


FIG. 88.—NEMESTRINA LONGIROSTRIS.

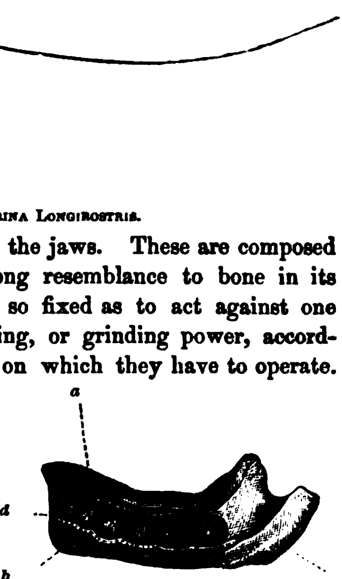


FIG. 89.—DEVELOPMENT OF TEETH.
a, the gum; *b*, the lower jaw; *c*, angle of the jaw; *d*, dental capsules.

in man constitutes nearly its whole structure; this conversion takes place first at its highest points, *d*, *d*. The *crown* or upper portion of the tooth receives a covering of *enamel*, a much harder substance, which is formed by the lining of the capsule. Gradually the process of conversion extends more and more to the interior of the pulp; and at last the whole is changed into ivory, with the exception of a small portion that still remains, occupying what is termed the cavity of the tooth, which is frequently laid open by decay of its external wall. As the root of the tooth is developed, the crown is gradually pushed upwards, so as to press against the upper portion of the capsule and the gum by which this is covered. These parts yield slowly to the pressure; and the tooth makes its way to the surface; or, in common language, is *cut*.

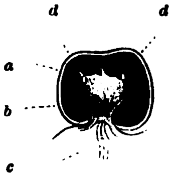


FIG. 90.—DENTAL CAPSULE.

175. The process of cutting teeth is usually not a severe one in the healthy and well-managed infant; but it occasions the death of vast numbers of children who are injudiciously treated; and it is especially fatal to those who have a tendency to disease of the nervous system. The irritation caused by the pressure of the tooth against the gum, is liable to excite, in such cases, convulsive actions of various kinds, on the principles hereafter to be explained (Chap. x.); and as the removal of the source of irritation, in such cases, is of the greatest importance, the lancing of the gums,—doing that in an instant which the pressure of the tooth might not accomplish for days,—is a measure of most obvious utility; however unnecessary it may seem, in ordinary cases, to interfere with the course of nature.

176. At the same time that the development of the tooth is thus taking place, the bone of the jaw is becoming hardened; and closes round its root, forming a complete socket. This partly interrupts the passage of vessels and nerves to the tooth, which, when once fully formed, seems to acquire no further growth, and not to possess the power of repairing injuries occasioned by disease or accident. Hence a tooth which is broken or decayed, is not restored as a bone would be. Still, however,

its root or fang is penetrated by a small nerve and artery, which are distributed to the membrane that lines the cavity; and it is to the action of air upon the former, when the cavity is laid open by decay, that the pain of tooth-ache is chiefly due. The remedies which are most effectual in removing this pain, such as kreosote, nitric acid, or a heated wire, are those which destroy the vital power of the nerve.

177. But there are teeth, in many animals, which never cease to grow, and in which the central cavity is always filled with pulp. Such have no proper root; for additional matter is being continually formed at their base, and thus the whole tooth is pushed upwards. This is the case with the Elephant's tusks; and also with the large teeth that occupy the front of the jaw in Rabbits, Squirrels, Rats, and other gnawing animals (Fig. 91). The upper edges of these teeth are being constantly worn away by use; but they are kept up to their proper level by the growth of the tooth from below. But it sometimes happens that one of these teeth is broken off; and the one *opposite* to it in the other jaw is then thrown into disuse. It continues, however, to grow up from below; but, not being worn down at the top, its length increases greatly, so that it may become a source of great inconvenience to the animal.

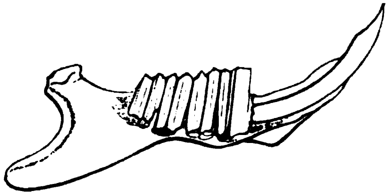


FIG. 91.—JAW AND TEETH OF RABBIT.

178. The teeth are generally made up of two or more distinct substances, differing in structure and properties. That which usually forms their principal part, is termed the *ivory*; but the summit or crown of the tooth is generally clothed with a much harder substance, which is termed *enamel;* and its fang is covered with a substance closely resembling bone, and termed the *cortical* substance. Although the ivory, enamel, and cortical substance occupy these different positions in most teeth, they are all mixed together (as it were) in the grinding teeth of many herbivorous animals, to answer a particular purpose (§. 182).

179. All these substances contain a large proportion of mineral matter. The amount is the greatest in the enamel, which is generally hard enough to strike fire with steel; this does not contain above two parts in one hundred of animal tissue. In the ivory, the proportion of animal matter is larger, varying from 20 to 29 per cent. And in the cortical substance, it is about 42 per cent.; which is nearly the same proportion as that which exists in bone. Of the mineral matter by far the largest part consists of phosphate of lime; most of the remainder being the carbonate of lime (the same as limestone or chalk).

180. When examined with the microscope, the Ivory is seen to contain a number of very minute wavy tubes, which commence in the central cavity and pass towards the surface of the teeth; these appear analogous to the minute tubes which have been described as contained in Bone (§. 48). The Enamel, when examined in a similar manner, is seen to consist of a multitude of six-sided columns or *prisms*, packed closely against each other, and directed perpendicularly to the surface on which they lie, so that one of the extremities of each column rests upon the ivory, whilst the other helps to form the surface of the tooth. When the mineral matter is dissolved away by an acid, the remaining very delicate animal tissue still presents the same form; so that we may regard it as composed of a number of six-sided prismatic cells, precisely resembling those of Plants (See VEGET. PHYS. §. 71), in which the mineral matter is deposited. The structure of the Cortical substance is of the same character with that of Bone, but is less regular.

181. In Man, and most of the other Mammalia, there are three kinds of teeth, adapted for different purposes. The first terminate in a thin cutting edge, and are intended simply to *divide* the food introduced into the mouth; these are termed *incisor* teeth (Fig. 92). Others have more of a conical form, and in many animals (especially those of carnivorous habits) project far beyond the former; they are not adapted to cut the food, but, by being deeply fixed in it, to enable the animal to tear it asunder: these are termed *canine* teeth. The teeth of the third kind have a large irregular flattened surface, and are

adapted to bruise and grind the food; these are called *molar* (or mill-like) teeth. The manner in which these different teeth are implanted in the jaw, varies with the form of their crown, and is in accordance with their several uses. The incisors, whose action tends rather to bury them in their sockets, than to draw them forth, have but a single root or fang of no great length. The canine teeth, on which there is often considerable strain, penetrate the jaw more deeply than the incisors; especially when they are large and long, as in the cat tribe (Fig. 93). And the molars, whose action requires great firmness, have two, three, or even four roots or fangs, which spread out from each other; and these at the same time increase the solidity of their attachment to the jaw, and prevent the teeth from being forced into their sockets by any amount of pressure.

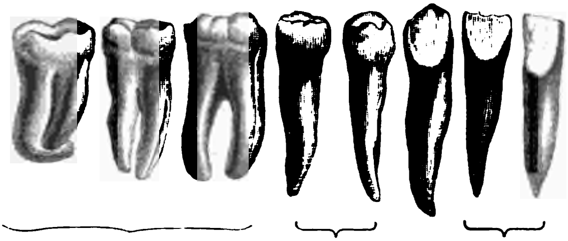


FIG. 92.—HUMAN TEETH.

182. The arrangement of the dental apparatus varies, in different Mammalia, according to the nature of the aliment on which they are destined to feed; and this correspondence is so exact, that the anatomist can generally determine, by the simple inspection of the teeth of an animal, not only the nature of its food, but the general structure of the body, and even its ordinary habits. Thus, in those that feed exclusively on animal flesh, the molar teeth are so compressed as to form cutting edges, which work against each other like the blades of a pair of scissors (Fig. 93); whilst in animals that live on insects, these teeth are raised into conical points, which lock into corresponding depressions in the teeth of the opposite jaw (Fig. 94). When the nourishment of the animal consists principally of soft

fruits, these teeth are simply raised into rounded elevations (Fig. 96); and when they are destined to grind harder vegetable substances, they are terminated by a large flat and roughened surface (Fig. 95). The roughness of this surface is maintained, by the peculiar arrangement of the three substances, of which the tooth is composed. The enamel, instead of covering its crown, is arranged in upright plates, which are dispersed through the tooth; and the space between them is filled up by plates of ivory and of cortical substance. These last, being softer than the enamel, are worn down the soonest; and thus the plates of enamel are left constantly projecting, so as to form a rough surface, which is admirably adapted to the grinding action the tooth is destined to perform. In the great gnawing teeth of the squirrel, &c., the front surface only is covered with enamel; and as this is worn away more slowly than the ivory, it stands up as a sharp edge (Fig. 91), which is always retained, however much the tooth may be worn away.

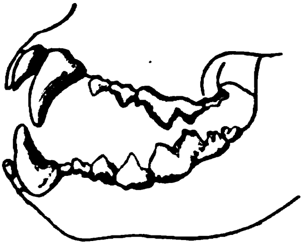


FIG. 93.—TEETH OF CARNIVOROUS ANIMAL.

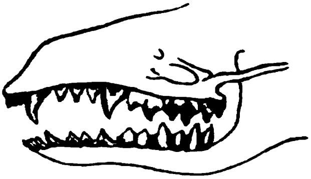


FIG. 94.—TEETH OF INSECTIVOROUS ANIMAL.

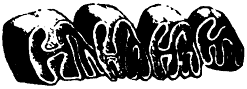


FIG. 95.—TEETH OF HERBIVOROUS ANIMAL.

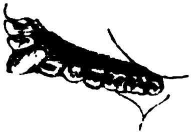


FIG. 96.—TEETH OF FRUGIVOROUS ANIMAL.

183. Of all the teeth, the molars may be regarded as the most useful. They are seldom absent in the Mammalia; and their office is usually essential to the proper digestion of the

food. Animal flesh (the most easily digested of all substances) needs but to be cut in small pieces; but the hard envelopes of beetles and other insects must be broken up; and the tough woody structure of the grasses, and the dense coverings of the seeds and fruits on which the herbivorous animals are supported, must be ground down. The incisors and canines are chiefly employed among carnivorous animals, for the purpose of seizing their living prey, and are never deficient in them; but they are less required in herbivorous animals; and either or both kinds are not unfrequently deficient. Sometimes, however, they are not only present, but are largely developed, serving as weapons of attack and defence; as in the Boar (Fig. 97).

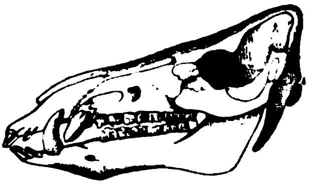


FIG. 97.—SKULL OF BOAR.

184. There are a few Mammalia which do not possess teeth. This is the case with the common Whale, in which they are replaced by an entirely different structure. From the upper jaw there hang down into the mouth a number of plates of a fibrous substance, to which we give the name of *whalebone*, though it is really analogous to the *gum* of other animals. The fibres of these plates are separate at their free extremities, and are matted, as it were, together, so as to form a kind of sieve. Through this sieve water is drawn, in enormous quantities, whenever the Whale is in want of food; and in this manner it strains out, as it were, the minute gelatinous animals upon which it lives,—such as the little Pteropods (§. 122) and Medusæ (§. 130), which abound in the seas it inhabits. The water thus taken in is

FIG. 99.
WHALEBONE.

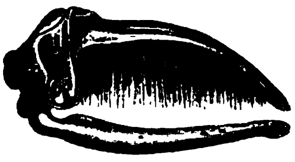


FIG. 98.—SKULL OF WHALE.

expelled from the nostrils or blow-holes, which are situated at the top of the head. Most of the Whale tribe have short fringes of this kind, in the roof of the mouth; but in none, except the *Balæna*, or Greenland whale, is it long enough to make it worth separating, all the other species having teeth, either in one or both jaws. It is a curious fact, that the rudiments of teeth may be discovered in *both* jaws of the young Greenland whale, although they are never to be developed. And the rudiments of incisor teeth in the upper jaw, and of canine teeth in both jaws, may also be discovered in the young of the Ruminant quadrupeds (oxen, sheep, &c.), though they never show themselves above the gum.

185. The Ant-eaters, also, are destitute of teeth, and usually obtain their food by means of their long extensible tongues, which are covered with a viscid saliva; this being pushed into the midst of an ant-hill, and then drawn into the mouth, brings into it a large number of these insects, which are sufficiently bruised between the toothless jaws.—Lastly, may be mentioned as a curious exception

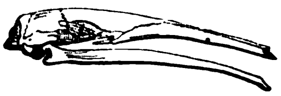


FIG. 100.—SKULL OF THE ANT-EATER.

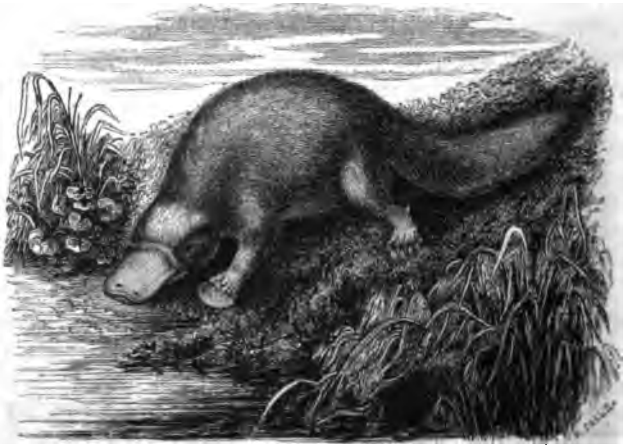


FIG. 101.—ORNITHORHYNCUS.

to the general rules respecting the teeth of Mammalia, the remarkable *Ornithorhyncus*, or *Duck-billed Platypus* of New Holland (Fig. 101). This animal feeds, like the duck, upon the water insects, shell-fish, and aquatic plants, that it obtains from the mud, into which it is continually plunging its singular bill; and its jaws, entirely destitute of teeth, are furnished with horny ridges, by which it can in some degree masticate its food.

186. Among Birds, there is an entire absence of teeth; and the mechanical division and the reduction of food is performed in the stomach, in the manner hereafter to be mentioned (§. 200). The mouths of almost all Reptiles, excepting the Turtle tribe, are furnished with numerous teeth; but these are not adapted for much variety of purposes, being principally destined to prevent the escape of the prey which the animals have secured; and their shape is consequently nearly uniform, being for the most part simply conical. There are some Lizards, however, which are herbivorous; and these have large rough teeth, somewhat resembling the molars of Mammalia. Animals of this tribe attained a gigantic length, not less than from 90 to 120 feet, in past ages of the world.—In Fishes, the teeth are commonly very numerous; but they have for their object only to separate and retain their food; and there is little variety in their form. Frequently they have no bony attachment, being only held by the gum as in the shark; and they are consequently often torn away, but they are as readily replaced. Sometimes, however, the tooth seems like a continuation of the bone of the jaw, not being in any way

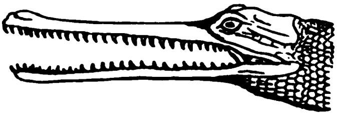


FIG. 102.—HEAD OF GAVIAL (CROCODILE OF THE GANGES).

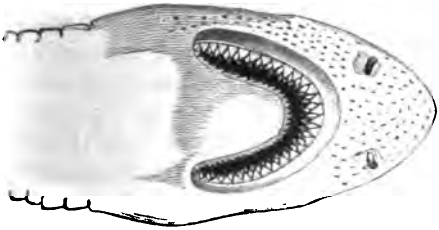


FIG. 103.—HEAD OF SHARK.

separated from it, and the tubular structure of the latter being continued into it without any interruption. The teeth of Fishes are often set, not only upon the proper jaw-bones, but upon the surface of the palate, and even in the *pharynx* or swallow.—In the Invertebrata, there are generally no proper teeth; but in both the Articulated and Molluscous series, we very commonly meet with firm horny jaws, which are often furnished with projections that answer the same purpose. It is very remarkable, however, that in an animal so low in the scale as the *Echinus* or Sea-Urchin (§. 128), a very complex dental apparatus should exist. This consists of five long hard teeth, which surround the mouth; and these are fixed in a framework, which is worked by a powerful set of muscles, and thus serve effectually to grind down the food, which seems to be chiefly of a vegetable nature.

187. In the Mammalia in general, as in Man, the teeth are not much developed at the time of birth, that they may not interfere with the act of sucking; and they do not make their appearance above the gum, until the time approaches when the young animal has to prepare its own food, instead of simply receiving that which has been prepared by its parent. The teeth which are first formed are destined to be shed after a certain period, and to be replaced by others. They are called *milk teeth;* and in Man they are 20 in number,—namely, four incisors in the front of each jaw, and two canines and four molars on each side. They begin to fall out at about the age of seven years; previously to which, however, the first of the permanent molars appears above the gum, behind those of the first set. The incisors and canines of the first set are replaced by incisors and canines respectively; but the molars of the first set are replaced by teeth like small molars, having only two fangs; these are called false molars, or, more properly, *bicuspid* teeth (Fig. 92). The second of the true molars does not make its appearance until all the milk teeth have been shed; since it is only then that the jaw becomes long enough to hold any additional teeth. The third does not usually come up until the growth of the jaw is completed; and as this time corresponds with that at which the mind as well as the body is matured, they are commonly

known as *wise* or *wisdom teeth*. There are then 32 teeth in all, or 16 in each jaw;—namely, four incisors, two canines, four bicuspid, and six true molars.—In extreme old age, these teeth fall out like those of the first set; but they are not replaced by others, and their sockets are obliterated.

188. The teeth are but passive instruments in the act of mastication. They are put in movement by the jaws in which they are fixed; and these are made to act against each other by various muscles. The upper jaw is usually fixed to the head; and has not, therefore, any power of moving independently of it. But the lower jaw is connected with the skull by a regular joint on either side; and is so moved by the muscles attached to it, as to cut, crush, or grind the food, according to the nature of the teeth. There is considerable variety, in different animals, as to the extent of motion which the lower jaw possesses. In the purely carnivorous quadrupeds, it has merely a hinge-like action, that of opening and shutting; and by the sharpness of the edges of the molar teeth, it is thus rendered a powerful cutting instrument. But in the herbivorous animals, which have to grind or triturate their food between the roughened surfaces of their molars, such a limited motion would be of no avail; and we accordingly notice, if we watch an ox or a horse whilst masticating its food, that the lower jaw has considerable power of motion from side to side. On the other hand, in the gnawing animals, furnished with two large front teeth, the lower jaw has no power of moving from side to side, but is rapidly drawn backwards and forwards; and, as the ridges of the molar teeth are arranged in the opposite direction, they become very powerful filing instruments, by which the toughest vegetable substances are quickly reduced.

189. In the Human jaw, there is a moderate power of motion in all these different directions; and it is furnished with all the muscles by which they are effected, in the different animals that perform them; but these are not so large or strong. The most powerful of the muscles of the lower jaw, in all animals, is that by which it is drawn up against the upper, so as to close the mouth. This arises from the side of the skull in the region of the temple,

and is hence called the temporal muscle. It covers at its origin a large surface of bone; but its fibres approach one another as they descend, and pass under a bony arch (which may be felt between the cheek and the ear), to attach themselves to a process or projection of the lower jaw (*a*, Fig. 104), about an inch in front of the joint. As the distance from the fulcrum, of the point at which the power is applied, is thus much less than that of the front of the jaw, where chiefly the resistance is encountered, the power of the muscle is applied at a mechanical disadvantage; and, to overcome a given resistance, the muscle must itself be several times more powerful. Thus the tiger and lion, which can lift and carry away the bodies of animals weighing several hundred pounds, must possess temporal muscles that shall contract with a force of two thousand, or even more (MECHANICAL PHILOSOPHY, §. 292).

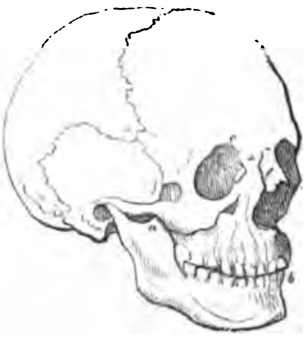


Fig. 104.

Insalivation.

190. The act of mastication is connected with another; which is also of great importance in preparing for the subsequent process of digestion. This is the blending of the saliva with the food, during its reduction between the teeth,—an act which is termed *insalivation*. The saliva is separated from the blood, by glands which are situated in the neighbourhood of the mouth; of these there are three pair in man, two beneath the tongue (Fig. 105), and one in the cheek, each pouring in its secretion by a separate canal. The salivary fluid is principally composed of water, in which a small quantity of animal matter and some saline substances (chiefly common salt) are dissolved; the whole amount of these, however, is not more than 1 part in 100. The secretion of saliva is not constantly going on; but the fluid is formed as it is wanted. The *stimulus* by which the gland is set

in action may be simply the motion of the jaws; thus, on first waking in the morning, the mouth is usually dry, but it is soon rendered moist by the movements which take place in speaking. The contact of solid substances with the membrane lining the mouth appears also to excite the flow; hence dryness of the mouth may often be remedied for a time, when no water is at hand, by taking a pebble into the mouth, and moving it from side to side. Every one knows, too, that the simple *idea* of savoury food will excite an increased flow; making the "mouth water," as it is popularly termed. These are instances of the power of the nervous system, through which the impressions are conveyed, over the act of secretion.

191. There are certain kinds of food, in which the admixture of saliva appears to occasion the commencement of those chemical changes in which digestion consists; but in general, the benefit derived from this process of insalivation is just that which is obtained by the chemist, when he bruises in a mortar, with a small quantity of fluid, the substances which he is about to dissolve in a larger amount. If the preliminary operations of mastication and insalivation be neglected, the stomach has to do the whole of the work of preparation, as well as to accomplish the digestion; thus more is thrown upon it than it is adapted to bear; it becomes over-worked, and manifests its fatigue by not being able to discharge even its own proper duty. Thus the digestive function is seriously impaired, and the general health becomes deranged in consequence. A malady of this kind is very prevalent in the United States; and is almost universally attributed by medical men, in part at least, to the general habit of very rapidly eating or rather *bolting* the meals. There is another evil attendant on this practice,—that much more food is swallowed, than is necessary to supply the wants of the system; for the sense of hunger is not so readily abated by food which has not been prepared for digestion; and thus the feeling of satiety is not produced, until the stomach has already received a larger supply than it is well able to dispose of. Imperfect mastication of the food is very apt to occur, in persons who are losing their teeth by old age or decay; and where these are not replaced

by artificial means, the next best remedy is to cut the food into very small portions, before it is taken into the mouth, and to masticate it there as thoroughly as possible.

Deglutition.

192. In the Mammalia, the cavity of the mouth is guarded behind by a sort of movable curtain, which is known as the *veil* of the palate (Fig. 105); and this hangs down during mastication, in such a manner as to prevent any of the food from passing backwards. This partition, which does not exist in Birds and other animals that do not masticate their food, hangs from the arch and sides of the palate, so as to touch the tongue by its lower border; but it can be lifted in such a manner as to give the food free passage beneath it, into the top of the gullet. When mastication is completed, the food is collected on the back of the tongue into a kind of ball; and this, being carried backwards by the action of its muscles, presses against the partition just mentioned, and causes it to open. The food thus passes

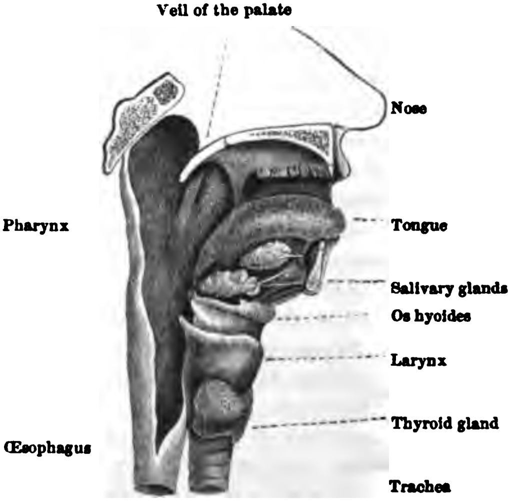


Fig. 105.—Perpendicular Section of the Mouth and Throat.

into a sort of funnel, formed by the expansion of the top of the *œsophagus* or gullet; this cavity, termed the *pharynx*, communicates above with the nostrils, and in front with the *larynx*, which is at the top of the windpipe. The *œsophagus* is a long and narrow tube, which descends from the pharynx to the stomach, lying just in front of the vertebral column, and behind the heart and lungs. It is surrounded by muscular fibres, disposed in various ways; by the action of which the food that has once passed into the pharynx is propelled downwards to the stomach.

193. But in order to reach this tube, the alimentary ball must pass over the glottis, or aperture of the windpipe. In order to prevent its falling in, the larynx is drawn, in the very act of swallowing, beneath the base of the tongue; and this action presses down a little valve-like body, the epiglottis, upon the aperture, so as in general effectually to prevent any solid or fluid particles from entering it. But it sometimes happens that, if the breath be drawn in at the moment of swallowing, a small particle of the food, or a drop of fluid, is drawn into the glottis; and this action (commonly termed "passing the wrong way,") excites a violent coughing, the object of which is to drive up the particle, and to prevent it from finding its way into the lower part of the windpipe. It may also happen that a larger substance may slip backwards, by its own weight, into the glottis, when there was no intention of swallowing, and when the larynx was consequently not drawn forwards beneath the tongue. The presence of such a substance in the windpipe excites a violent, and frequently almost suffocating cough (§. 342); the effect of which is sometimes to drive it up through the glottis, and thus to get rid of the source of irritation.

194. But if this does not occur, it is necessary to remove the offending body in other ways; sometimes it may be removed by an aperture made in the windpipe; but if it cannot be laid hold of and drawn through this, the plan recently adopted in the case of Mr. Brunel (the celebrated engineer) into whose windpipe a half-sovereign had unfortunately found its way, may be advantageously employed. He was fixed upon a board that was made

to revolve upon a pivot, in such a manner that his body was brought into a very inclined position, with the head *downwards*, a position which could not, of course, be retained for a long time at once. The coin then dislodged itself by its own weight, from its place in one of the bronchial tubes (§. 328), and was felt to drop towards the glottis. But it there produced so violent an irritation, as to bring on a cough which threatened suffocation; and the attempt was abandoned. It was renewed on another occasion, however, after an opening had been made into the windpipe (for the purpose of extracting the coin through it, which was attempted unsuccessfully); and as the admission of air into the lungs through this opening prevented any chance of suffocation, the inclined position of the body was continued, until the coin dropped through the glottis into the mouth.

195. The act of swallowing is itself involuntary, and may be even made to take place against the will. This may seem contrary to every one's daily experience; but it is nevertheless true. The movement by which the food is carried back, beneath the arch of the palate, into the pharynx, is effected by the will; but when it has arrived there, it is laid hold of, as it were, by the muscles of the pharynx, and is then carried down involuntarily. It has several times happened, that a feather, with which the back of the mouth was being tickled to excite vomiting, having been introduced rather too far, has been thus grasped by the pharynx, and has been swallowed. Moreover, we cannot perform the act of swallowing, without carrying *something* backwards upon the tongue; and it is the contact of this *something*, even if it be only a little saliva, with the membrane lining the pharynx, that produces the muscular movement in question. This action is one of the kind now denominated *reflex*. It is produced through the nervous system; for if the nerves supplying the part be divided, it will not take place. But it does not depend upon the *brain;* for it may be performed after the brain has been removed, or when its power has been destroyed by a blow. It is caused by the conveyance to the top of the Spinal Cord, of the impression make on the lining of the pharynx; this impression, conveyed through one set of nerves, excites in the

spinal cord a motor power; which, being transmitted through another set of nerves, calls the muscles into action.

196. This action is, therefore, *necessarily* connected with the impression; so long as this portion of the spinal cord, and the nerves proceeding from it, are capable of performing their functions: and it is one of those to which we may give the name of *instinctive*, to distinguish it from those which are effected by an effort of the will, intentionally directed to accomplish a certain purpose. It may even take place, without the animal being aware of the contact of any substance to be swallowed with the lining of the pharynx; for there is good reason to believe that when the brain has been destroyed, or paralysed by a blow, all sensibility is destroyed; and we have also sufficient reason to consider it as suspended in profound sleep or apoplexy; in which states swallowing is still performed. In the severest cases of apoplexy, however, the power of swallowing is lost; and this is a symptom of great danger, since it shows that not the brain alone, but the upper part of the spinal cord, is suffering from the pressure; and that the movements of respiration, which depend upon a similar action of the nervous system (Chap. VI.) will probably soon cease, so that death must ensue.

Chymification.

197. The food, thus propelled downwards by the action of the muscles of the pharynx and of the œsophagus (gullet) arrives in Man and the Mammalia, at the *stomach;* which is a large membranous bag, placed across the upper part of the abdomen (Fig. 106). The form of this stomach varies much, according to the nature of the aliment to be digested. Where the food is animal flesh, which is easily dissolved, the stomach is small, and appears like a mere enlargement of the digestive tube; this is the case in the Cat tribe, for example. In Herbivorous animals, on the contrary, the stomach is very large, the food being delayed there a long time on account of the difficulty with which it is digested; and the principal part of its cavity is not a simple enlargement of the digestive tube, but a bag or sac that bulges out, as it were, on the left side of that canal. By the degree of

this bulging, we can judge of the nature of the food on which the animal is destined to live. Thus in Man (Fig. 106), the large end of the stomach, situated on the left side (the *right* side of the figure as we look at it) is moderately developed; showing, as we might expect from the form of his teeth, as well as from his natural tastes, that he is adapted for a diet in which animal and vegetable food are mixed. In the purely carnivorous tribes, this large end of the stomach is almost deficient; whilst in the herbivorous races, it is enormously developed, and sometimes forms a distinct pouch.

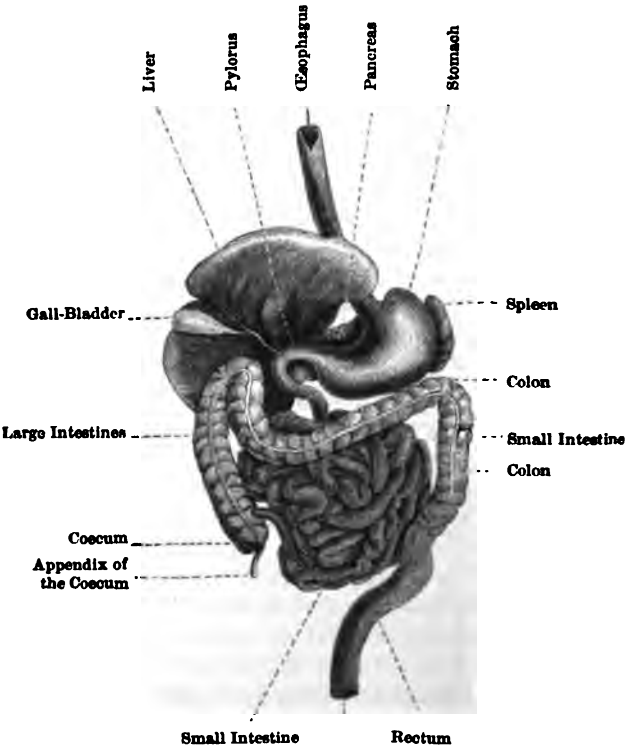


Fig. 106.—Digestive Apparatus of Man.

198. The most complex form of the stomach among Mammalia, is that which we find in the animals that *ruminate* or chew the cud. It possesses, in fact, no less than four distinct cavities, through all of which the food has to pass, during the process of digestion. The external appearance of the stomach of the Sheep is seen in Fig. 107; and its interior is displayed in Fig. 108. The food of the Ruminant animals is not chewed by them, before it is first swallowed. In their wild state, they are peculiarly exposed to the attacks of their carnivorous enemies, when they come down from their rocky heights to browse upon the rich pastures of the valleys. If they were then obliged to masticate every mouthful, they would be exposed to long-continued danger at every meal; but, by the curious construction of the digestive apparatus, this is spared to them; for they are enabled to swallow their food as fast as they can crop it, and afterwards to return it to their mouths, and masticate it at their leisure, when they have retreated to a place of safety. The crude unmasticated food, which is brought down by the œsophagus, first enters the large cavity on the left side, which is commonly termed the *paunch*. It is there soaked, as it were, in the fluid secreted by its walls; and is then transmitted to the second cavity, which, from the sort of network produced by the irregular folding of its lining membrane, is called the *reticulum* or *honey-comb stomach*. This stomach also has a direct communication with the œsophagus,

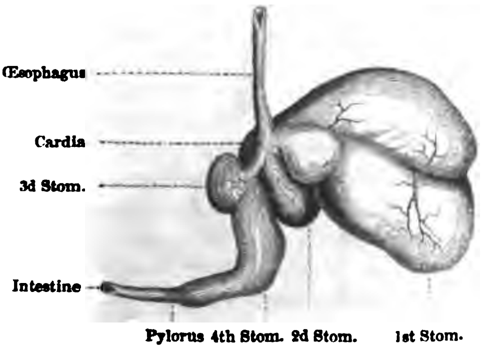


FIG. 107.—STOMACHS OF THE SHEEP.

and appears destined especially to receive the fluid that is swallowed; for this passes immediately into it, without going into the first stomach at all. The folds of its lining membrane seem destined to present a large surface, through which fluid may be absorbed into the system. It is here that we find the curious arrangement of water-cells in the stomach of the Camel; by which that animal is enabled to retain a supply of water for several days. These cells are nothing else than the little pits which are seen in the honey-comb stomach of the Sheep; they are much deeper, however, and each may be closed at the top by the drawing-together of its orifice. This is accomplished by a set of muscular fibres which form a net work, passing in every direction round the orifices; and a similar arrangement of these fibres is seen even in Man, in whose stomach the cells do not exist.

199. In the second stomach, the food transmitted from the first is rolled up, as it were, into balls, which are returned at intervals to the mouth. There they are completely reduced by mastication and insalivation; and are then ready for the real process of digestion. It is this mastication which is commonly known as the "chewing of the cud;" and the animal, whilst performing it, seems the very picture of placid enjoyment. When again swallowed, the food is directed, by a peculiar valvular groove at the bottom of the œsophagus, into the third stomach, commonly termed the *manyplies*, from the peculiar manner in which its lining membrane is arranged. This presents

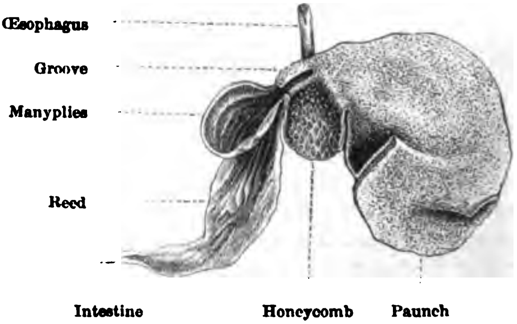


FIG. 108.—SECTION OF THE STOMACHS OF THE SHEEP.

a number of folds, lying nearly close to one another, like the leaves of a book, but all directed, by their free edges, towards the centre of the tube,—a narrow fold intervening between each pair of broad ones. The food has, therefore, to pass over a large surface, before it can reach the outlet of the cavity; and this leads to the fourth stomach, commonly termed the *reed*. This is the seat of the true process, the gastric juice (§. 204) being formed here only; and it is from this that the *rennet* is taken, which is used in making cheese, to cause the milk to coagulate or curdle. In the sucking animal, the milk passes directly into this fourth stomach, without entering either the first or second stomachs, and without being delayed in the third, the folds of which adhere together at that time, so as to form a narrow undivided tube. The paunch is at that time comparatively small, being of less size than the reed; and its dimensions increase, as soon as the young animal begins to distend it by swallowing solid vegetable matter.

200. In the digestive apparatus of Birds, we find a considerable modification of form, resulting from the fact that, as these animals do not masticate their food, they require some other means of reducing it. This means is provided for them in their stomach. In the tribes whose food is of such a nature as to require being moistened before it is rubbed down, and especially in those which feed upon grains, the œsophagus has a pouch-like dilatation, termed the *crop* or *craw;* in this it is retained, and exposed to the action of fluid secreted by its walls, just as it is in the paunch of ruminant quadrupeds. This crop is of enormous size in some of the *granivorous* (grain-eating) birds, such as the Turkey. The second stomach (or *ventriculus succenturiatus*) is the one in which the gastric juice is secreted; but this is seldom large enough to retain the food, which passes on through it to the gizzard, a hollow muscle, furnished with a hard tendinous lining. In the granivorous birds this is extremely strong and thick; and pieces of gravel are swallowed by them, which, being worked up with the food by the action of the gizzard, assist in its reduction. In the rapacious flesh or fish eating birds, however, no such assistance is required, the food being easy of

solution; the walls of their gizzard are consequently thin, possessing but few tendinous fibres; and the three cavities of the stomach are almost united into one.

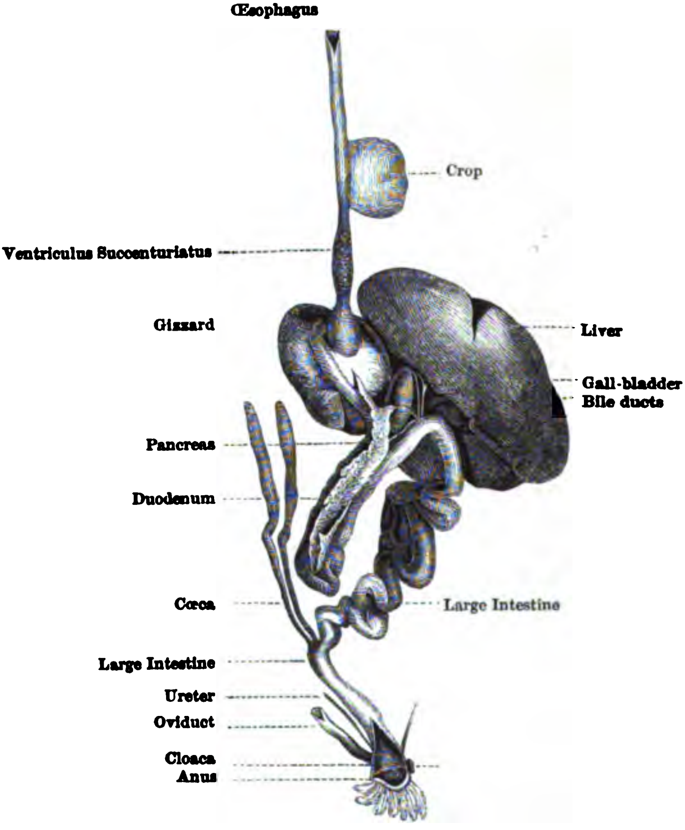


FIG. 119.—DIGESTIVE APPARATUS OF FOWL.

201. Various experiments have been made to test the mechanical powers of the gizzard of Birds. Balls of glass which they were made to swallow with their food, were soon ground to powder; and the points of needles and of lancets, fixed in a ball of lead, were blunted and broken off by the power of the

gizzard, whilst its own internal coat did not appear to be in the least injured. On the other hand it has been ascertained, that grain enclosed in metal balls which protected it from the mechanical action of the gizzard, but which were perforated so as to afford the gastric fluid free access to their contents, was not in the least digested; so that the utility, and even the necessity of this operation, become evident.

202. As there are few animals, save the Mammalia, that perform any proper mastication in their mouths, the grinding down of their food (where it is of such a nature as to require it) must be performed in their stomach; and accordingly we find many tribes, belonging to different divisions of the animal kingdom, in which a gizzard, or something analogous to it, exists. It is possessed by almost all the Cephalopoda, and by many of the Gasteropoda. In the walls of the stomach of one of these last, there is a considerable amount of mineral matter deposited; intermixed with the hard tendinous fibres of which they chiefly consist. A powerful gizzard is also found in many Insects, but here it is placed *above* the digestive stomach (Fig. 110, *c*). The accompanying figure exhibits the alimentary canal of a Beetle, from its commence-

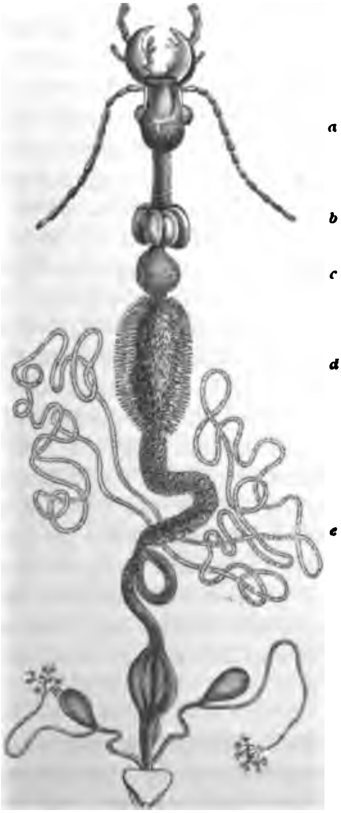


FIG. 110.—DIGESTIVE APPARATUS OF BEETLE.

ment to its termination. At *a* is seen the head, bearing the jaws, &c.; from this the gullet passes straight backwards, and is dilated into a crop at *b*, below which is the gizzard, *c*. This opens at its lower end into the true digestive stomach, *d*; which is surrounded by an immense number of little *follicles* or bags, by which the secretion of the *gastric juice* is effected (§. 204). Into the lower end of this, the long vessels, *e*, open, which constitute in Insects the only rudiment of a liver (Chap. VIII.). In many of the Crustacea, the walls of the stomach are beset with regular rows of teeth, which are moved by the action of powerful muscles. These teeth are cast or shed at the same time with the shell. In the higher Polypes it will be remembered that a gizzard exists between the œsophagus and the true digestive stomach; and the stomach itself is surrounded by the little follicles which secrete the bile, and pour it into that cavity (§. 134) In the Rotifera, the place of the gizzard is occupied by a curious pair of jaws, armed with teeth; by the working of which, the food is effectually crushed (§. 117).

203. In animals which subsist exclusively on flesh, however, no such complicated apparatus exists. Thus in Serpents, the stomach is but a slight dilatation of the alimentary tube; and it is not easy to say where it commences and terminates. In Spiders and Scorpions, too, which live upon the juices they suck from other animals, the alimentary tube is very simple; and is scarcely dilated into a proper stomach. And in most of the Radiated classes, we find the stomach to possess only one orifice, through which the undigested residue of the food is cast out, as well as fresh supplies taken in (§. 14). But this stomach is not always a simple bag; thus in the *Star-fish* it sends prolongations into the rays, the use of which is at present unknown.

Nature of the Digestive Process.

204. The food which has been *reduced* in the mouth by the action of the teeth, or in the stomach itself by the movement of its own tendinous walls, is prepared for the real process of *digestion;* by which it is converted into a fluid, and thus made fit to be truly received into the system, by being absorbed

into its vessels. The chief agent in the digestive process is a fluid termed the *gastric juice*, which is secreted or separated from the blood by a vast number of little bags or follicles, imbedded in the walls of the stomach. When the cavity is empty, this fluid is secreted in very small quantities; but, like the salivary secretion, it is poured out in abundance, when the lining membrane is stimulated by the contact of food, especially solid food. But only a certain quantity is secreted at any one time; and this quantity is just that which is sufficient to dissolve food enough for the supply of the natural wants of the system. The contact of any solid substances with the interior of the stomach, is sufficient to produce a flow of this fluid into its cavity; but the secretion soon ceases, if the substance be not of an alimentary nature.

205. The sense of *hunger* appears due to the distention of the blood-vessels of the stomach, which takes place in preparation for the secretion of the gastric fluid. This determination of blood towards the stomach seems to occur whenever the body needs a fresh supply of nourishment; and it ceases as soon as a sufficient amount of gastric fluid has been drawn off. Hence it is, that hunger is relieved by eating; and hence it is, also, that hunger is for a time relieved by taking solid substances into the stomach, even though they contain no nourishing matter. It is from this cause, too, that savage nations are in the habit of mixing indigestible solid matter, with the fluids that sometimes constitute their principal articles of food. Thus the Kamschatdales mix earth or saw-dust with the train-oil, on which alone they are frequently reduced to live; and the Veddahs or wild hunters of Ceylon, on the same principle, mix the pounded fibres of soft or decayed wood with the honey, on which they feed when meat is not to be had. One of them being asked the reason of the practice, replied, "I cannot tell you, but I know that the belly must be filled." It has been found by experiment, that soups and other forms of fluid aliment are not alone fit for the support of the system, even though they may contain a large amount of nutritious matter; and the medical man well knows, that many persons have stomachs too weak and irritable to retain slops (as

they are commonly termed), who can yet digest solid food of a simple kind. All these instances show, that the contact of a solid substance with the walls of the stomach, is the proper stimulus or excitement to the secretion of the gastric fluid.

206. This fluid, when poured upon the food, is thoroughly mixed up with it by a peculiar movement of the walls of the stomach; which is continually bringing into contact with its sides, fresh portions of the alimentary mass, so that the whole is after a time equally exposed to the influence of the gastric fluid. If this movement were not to take place, only the outside of the mass would be digested, and the central portion would remain but little affected.

207. The nature of the gastric fluid, and the mode of its operation upon the food, have been studied by withdrawing a portion of it from the stomach, and by observing its properties and actions out of the body. A sufficient quantity for this purpose cannot be easily procured. Spallanzani, an Italian physiologist of the last century, contrived to obtain it, by causing birds and other animals to swallow sponges to which pieces of thread were attached; these, when they had remained long enough in the stomach to cause a secretion of the gastric juice, were drawn up again; and the fluid they had absorbed was pressed out into vessels, in which its properties could be examined. More recently, however, an advantageous opportunity has presented itself to Dr. Beaumont, an American physician, for obtaining supplies of gastric fluid in a less objectionable manner. A young man, named Alexis St. Martin, received a very severe wound in his left side, by the bursting of a gun; and although this wound had laid open the cavity of his stomach, he recovered his health completely, and subsequently married and had a family. There remained, however, an aperture in his stomach, which would not close up; and through this orifice, which was usually closed by a bandage, the contents of the stomach could be drawn out. The gastric juice was obtained by introducing an India-rubber tube into the stomach, when it was empty, and moving it about within the cavity; the contact of the tube then excited the follicles to secretion (on the principle already men-

tioned, §. 204); and the fluid thus poured into the stomach was drawn off through the tube.

208. The gastric juice is very like saliva in its appearance; but it is distinctly acid to the taste; and it is found, by chemical examination, to contain a considerable quantity of the muriatic and acetic acids*, in an uncombined state. Besides these, it contains a considerable quantity of animal matter which bears some resemblance to albumen; as well as other ingredients which seem to be of less importance. This fluid was found by Dr. Beaumont to possess the power of dissolving various kinds of alimentary substances, when these were submitted to its action at the constant temperature of 100° (which is about that of the stomach), and were frequently shaken up with it. The solution appeared to be in all respects as perfect, as that which naturally takes place in the stomach, but required a longer time. This is readily accounted for, when we remember that no ordinary shaking can produce the same effect with the curious movements of the stomach; and that the continual removal, from its cavity, of the matter already dissolved (which passes into the intestine), must aid the operation of the solvent upon the remainder.

209. It is a fact of great practical importance, that a certain quantity of the gastric fluid can act only upon a limited amount of alimentary matter; so that, if more food be taken into the stomach than the gastric fluid can dissolve, it remains there undigested. Now it has been already mentioned, that the quantity of the gastric fluid secreted at any one time is proportional, not to the amount of food in the stomach, but to the wants of the system; so that, if more food be swallowed than is required to repair the waste of the body, it lies for some time unchanged in the stomach, and becomes a source of irritation, which prevents the due discharge of its functions; and the evil goes on increasing with every addition to the contents of the cavity. This may not be *felt* by the individual at the time; but it leaves permanent effects, which manifest themselves sooner or later, in derange-

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* Muriatic acid is commonly known as *spirit of salt*; and acetic acid as *vinegar*.

ment of the general health. The habit of taking more food than is really necessary, and of irritating the stomach by stimulating substances or fluids (such as pepper, mustard, spirits, &c.), is a fertile source of disease. The injurious effects of these are manifested by the *thirst* which is the consequence of their use, and which is a call (as it were) on the part of the stomach, to prevent their irritating action by diluting them with water.

210. With regard to the precise mode in which the gastric fluid acts, in dissolving the substances introduced as food into the stomach, there is yet some uncertainty; although there can be no longer any reasonable doubt, that the operation is of a purely chemical nature. An artificial gastric fluid, capable of effecting all that can be done by that which is secreted in the living stomach, may be made, by macerating (or soaking) a portion of the membrane lining the stomach of a pig, or the fourth stomach of a calf (even after it has been washed and dried), in water made slightly sour with muriatic acid. It has been proved that both the acid and the animal matter are essential to the process of solution; for the acidulated fluid, without the animal matter, acts extremely slowly upon pieces of meat, hard-boiled egg, &c., submitted to it; and water in which the stomach has been macerated, but which contains no acid, will not act at all. But the acidulated water alone will readily dissolve the substances just mentioned, at a higher temperature; and thus it appears that the acid is the real solvent; and that the animal matter (to which the name of *pepsin* has been given) has for its office to produce some change in the alimentary substances, by which they are more readily dissolved. The recent inquiries of Liebig and other Chemists, render it probable that this change is of the nature of fermentation.

211. The food is thus reduced in the stomach to a kind of pulp, which is termed *chyme*. Its consistency will, of course, vary, according to the nature of the food, and the quantity of fluid in the stomach; but in general it is grayish, semi-fluid, and uniform throughout. When the food has been of a rich character, its aspect resembles that of cream; and when the food has consisted of farinaceous substances (rice, potatoes, &c.) the

chyme is more like gruel. At the point where the stomach opens into the intestinal canal, there is a kind of valve, which permits the chyme to pass as fast as it is formed, but closes against the portions of the food which are yet solid and undigested; and thus the chyme escapes from the stomach in successive waves, slowly at first, but afterwards more rapidly, as the digestive process comes near to its completion.

Chylification.

212. The blood-vessels, which are abundantly distributed on the walls of the stomach of higher animals, have the power of absorbing water from its cavity, and will also take up any thing that is completely dissolved in water; but they do not seem to have any share in the absorption of the alimentary matter, which is taken up by a peculiar set of vessels, that commence in the intestinal tube by a multitude of little rootlets, and are specially destined for this important function. These vessels are called *lacteals*, from the milky or white opaque appearance of the fluid they contain, which is termed *chyle*. This chyle is formed from the chyme, soon after the latter has quitted the stomach, by the mixture with it of the *bile*, which is secreted from the liver, and poured into the intestine near its commencement. The nature of the change thus effected is not well understood; but Dr. Beaumont found that, by mixing the chyme drawn from the stomach of his patient, with bile, it separated into three distinct parts,—a reddish-brown sediment at the bottom,—a whey-coloured fluid in the centre,—and a creamy layer upon the top. The sediment, partly consisting of the indigestible portion of the food, and partly of the colouring matter of the bile itself, is destined to be carried out through the intestinal tube, whilst the remainder is to be absorbed by the lacteals. The creamy layer consists of fatty particles, which seem partly derived from the food, and partly from the bile; and it is to the admixture of these in the chyle, that its milky aspect is chiefly due. The whey-looking portion probably consists of the *albuminous* matter which the food contained, now completely dissolved in water. The bile contains an alkali,

soda, which rather more than neutralizes the acid of the gastric fluid; so that the chyle now becomes rather alkaline than acid.

213. The process of digestion is by no means completed in the stomach; for much of the matter which escapes from it in the chyme is destined to undergo a further change, whilst passing through the intestinal canal; especially in the herbivorous tribes, whose food is less digestible than that of the carnivorous races, and requires to be long delayed in the intestinal canal, in order that it may yield up its nutritious portion. Hence we find this canal of enormous extent in most animals whose food is vegetable: thus in the Sheep it is about twenty-eight times the length of the body. But in the purely carnivorous animals it is comparatively short; thus in the Lion, it is only about three times the length of the body; and in the Serpent it runs almost straight from one extremity to the other (§. 94). In animals which live on a mixed diet, it is of medium length; thus in Man, the intestinal tube is about six times as long as his body. The intestinal tube is usually distinguished into the *small* and the *large* intestine; of which the small is the first portion, and the large the second. The former, as seen in Fig. 106, is disposed in a very much convoluted or twisted manner, so that a great extent of it may be packed within a small compass; it usually forms about three-fourths of the whole length of the canal. It is held in its place by a serous membrane termed the *peritoneum*, which forms an immense number of folds that suspend it (as it were) from the vertebral column; but these still allow it a considerable power of movement.

214. It is chiefly in the small intestines, that the process of digestion is continued; and it is from their walls, that the lacteals absorb the nutritious fluid. At the extremity of the small intestine, there is a kind of pouch, called the *cæcum;* which in some animals seems almost like a second stomach, and which is furnished with one or more little appendages, termed *cæca.*[*] This is very small in Man, and does not seem to perform any important function; but in most herbivorous animals it is larger

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[*] The word *cæcum* is used in Anatomy to denote a tube closed at one extremity.

(as in the Monkey, Fig. 19); and it is found to secrete an acid fluid, which resembles the gastric juice, and which may have for its office to perform a second digestion upon the substances which have escaped the first. These cœca are sometimes very large in the intestinal canal of Birds (Fig. 109). From the cœcum, the large intestine ascends as high as the liver, crosses the upper part of the abdomen, and then descends again, as shown in Fig. 106; this portion is termed the *colon;* and it terminates in the *rectum*, which forms the extremity of the intestinal tube.

215. The alimentary mass is propelled along the first part of the intestinal canal,—and the residue left after the absorption of the chyle is carried along the continuation of it,—by the contraction of its muscular coat, producing what is termed the *peristaltic motion* of the bowels. The fibres of this muscular coat are chiefly arranged in a ring-like manner around the tube; so that, when they contract, they narrow the diameter of the tube. They are stimulated to contract by the contact of the solid or liquid matter passing through it (Chap. XII.); and thus they force this matter onwards, into the succeeding portion of the tube. This contracts in its turn, and propels its contents further; and thus the mass is gradually driven from one extremity of the canal to the other. The peristaltic movement does not depend (as do the contractions of the muscles concerned in swallowing, §. 195) upon the nervous system; for it will take place after the intestinal tube has been completely separated from all its nerves; and also after the death of the animal, if this have been produced by a sudden cause. Thus, if a Rabbit be killed by a smart blow at the top of the neck, and the abdomen be immediately opened, the peristaltic movement will be seen in vigorous action, especially if the animal have eaten a full meal an hour or two previously.

Defecation.

216. In passing through the large intestine, the undigested residue is still more completely deprived of the alimentary matter it may contain; and its fluid portion is absorbed, so that it becomes more solid. It is allowed to accumulate in the rectum, until its bulk occasions inconvenient pressure upon the surround-

ing parts; and it is kept in by a circular muscle or *sphincter*, which surrounds the outlet of the alimentary canal. But when the accumulation has taken place beyond this amount, it excites a reflex action (§. 195) in the muscles that surround the abdomen; and these make pressure sufficient to overcome the resistance of the sphincter, and to force out the contents of the rectum.

Absorption of Chyle.

217. We have only now to inquire into the mode, by which the nutritive matter extracted from the food is taken up from the intestinal tube, and applied to the nutrition of the body. It has been already mentioned, that simple liquids may be absorbed by the veins; but the *selection* of the nutritive portion of the fluid in the intestines, is accomplished by the peculiar vessels already mentioned under the name of *lacteals*. These originate in the numberless *villi*, or minute projections, with which the mucous membrane that lines the alimentary tube is covered. Every one of these villi, indeed, may be regarded as a minute rootlet, analogous to the *spongioles* of plants (see VEGET. PHYS. §. 104), and having the absorption of nourishment for its object. It is copiously supplied with blood-vessels; and in its centre is the proper absorbent vessel, one of the commencements of a lacteal trunk. (*a a*, Fig. 2.) This vessel does not reach to the extremity of the villus, nor does it open at its point by any distinguishable aperture; but the end of the villus is formed of a loose tissue, in which, during the process of absorption, distinct *cells* may be seen in various stages of development. It appears almost certain, from the recent observations of Mr. Goodsir, that the absorption of chyle is really performed by these cells, of which a fresh crop (as it were) is produced every time that digestion takes place, and chyle is prepared. In the intervals, no cells can be seen in the ends of the lacteals; but they begin to be developed, from the germs that were left behind by the previous crop as soon as the chyle is prepared (*dd*, Fig. 2). Their growth is very rapid, and their life is transitory. In growing, they absorb into themselves part of the fluid that surrounds them; and it is probable that, when

they are mature, they either burst or dissolve away, and deliver this fluid to the absorbent vessels.

218. The vessels which thus originate, unite into minute trunks, and these again into larger ones; and these pass between the two layers of the *mesentery* (or fold of peritoneum by which the intestines are suspended, §. 213) towards the lower part of the spinal column: where they deliver their contents into a sort of reservoir, which thus becomes the receptacle for all the chyle that has been collected from the alimentary canal. In traversing the mesentery, however, the lacteals of the higher animals pass through little knot-like bodies of a peculiar nature, which are called (though improperly) mesenteric *glands*. When the structure of one of these is carefully examined, it is found to consist of one or more lacteal tubes, very much prolonged, and convoluted or twisted together; and of blood-vessels,

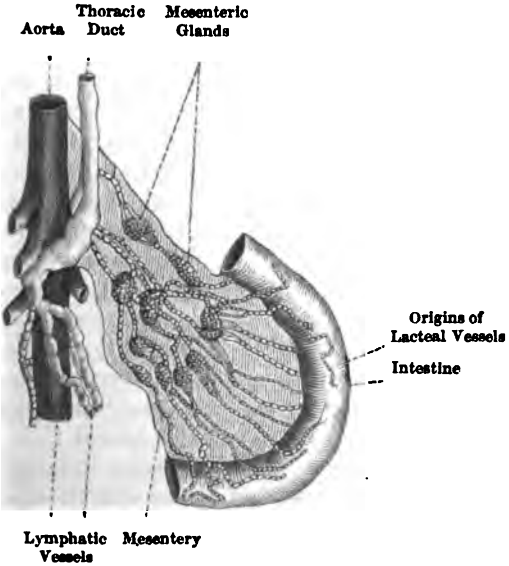

FIG. 111.—CHYLE-VESSELS.

which ramify in the midst of these convolutions, but do not really unite with them. In Reptiles, in which these glands do not exist, the absorbent vessels are much more extended and spread out than they are in Birds and Mammalia; so that the absence of the glands is in some degree compensated.

219. But the reservoir above mentioned receives, not only the *lacteal* vessels that bring nutritious matter from the intestinal tube, but also *lymphatics*, which are absorbent vessels of similar character, that originate in every part of the body. These, also, pass through a set of (so-called) glands, in their way towards this receptacle; and the structure of these glands, of which many are seated in the neck, some in the arm-pit, others in the groin, &c., is exactly the same as that of the mesenteric glands. The fluid they convey is of nearly the same character with that brought by the lacteals, and is evidently destined to be again applied to the purposes of nutrition. It has been stated (§. 53) that almost every part of the body is in a state of continual decay; and thus a quantity of organised matter is being constantly removed, being replaced by that which is newly formed. Of this, a portion is doubtless unfit to be retained within the body; and this is cast off by the various processes of Excretion: but it appears that another part may be again made use of; and that this is taken up by the lymphatics, and brought to the central receptacle to be mixed with the newly-absorbed chyle. Thus an animal may be said in some degree to live upon its own flesh; and there is no want of evidence that this is the case. Nor is there anything more strange in the conversion of some of the dead particles of the body itself into living tissues, than in the like conversion of similar dead particles derived from other animals, and taken in as food. The lymphatics also occasionally absorb substances that are placed in contact with the skin; and if these substances be of an irritating nature, they may occasion an inflammatory action in the absorbents, which may produce hardening and swelling of their glands. Thus when poisoned wounds in the hand have been received, as in opening the bodies of men or animals that have died of particular diseases, the effect is usually manifested at first by heat and pain in the arm,

along which the inflamed absorbents can be traced as hard cords; and the glands in the arm-pit become swelled and tender.

220. The lymphatics do not appear destined to absorb from the surface of the skin; this function being performed by the blood-vessels, which are distributed abundantly in its substance; and particularly by the veins. It is a fact now well established, that, when the amount of fluid in the body has been greatly reduced, absorption of water through the skin may take place o a considerable amount; and this even when the water is not applied to it in the form of liquid, but only in the state of vapour. Thus there is a case recorded by Dr. Currie, of a patient who suffered under obstruction of the gullet, of such a kind that no nutriment, either solid or fluid, could be received into the stomach; and who was supported for some weeks by immersion of his body in milk and water, and by the introduction of food into the lower end of the intestine. During this time, his weight did not diminish; and it was calculated by Dr. C. that from one to two pints of fluid must have been daily absorbed through the skin. The patient's thirst, which had been very troublesome previously to the adoption of this plan, was removed by the bath, in which he experienced the most refreshing sensations. It is well known that shipwrecked sailors and others, who are suffering from thirst, owing to the want of fresh water, find it greatly alleviated, or altogether relieved, by dipping their clothes into the sea, and putting them on whilst still wet. Even the moisture ordinarily contained in the atmosphere may be so rapidly absorbed, as sensibly to increase the weight of the body; and it would seem that a small quantity of spirit, or of hot fluid, taken into the stomach, has the power of peculiarly exciting this absorbent action. Dr. Watson mentions, in his Chemical Essays, that a lad at Newmarket, having been almost starved, in order that he might be reduced to the proper weight for riding a match, was found to have increased nearly thirty ounces within an hour, though he had only drank half a glass of wine in the interval. A parallel instance was related to the author by the late Sir G. Hill; in which the increase of weight was produced by drinking a single cup of tea, and was much greater in amount.

221. In the Invertebrated animals, neither lacteals nor lymphatics exist; and the blood-vessels, whose absorbent powers are so much restricted in the higher animals, have to perform the functions of these. We shall hereafter see (§. 235), that the fluid which circulates through their bodies has more resemblance to the chyle than it has to the blood of Vertebrata; being destitute of the peculiar red particles or floating cells from which the latter derives its colour, and not having the power of coagulating firmly.

Sanguification.

222. The chyle of Vertebrated animals, as taken up by the lacteals, may be regarded as blood in an early stage of its formation. It contains about 90 parts of water in 100; about 3½ parts of albumen, and the same of fatty matter; and about 3 parts of other animal and saline matter. Its appearance and characters differ, according to the part of the lacteal system from which it is drawn. If obtained near the surface of the intestines, before it has passed through the glands, it is entirely destitute of that power of spontaneously coagulating, or *clotting*, which is so remarkable in blood: and when examined with a microscope, it is seen to present a number of oily globules of various sizes; together with an immense number of very minute particles or molecules, which also seem of a fatty nature; and to these last, whose diameter is between 1-24,000th and 1-36,000th of an inch, the milky whiteness which characterises chyle seems principally due. But the chyle drawn from the lacteals, after they have passed through the mesenteric glands, possesses the power of coagulating slightly; hence it is evident, that some of the albumen has undergone a transformation into fibrin (§. 18). At the same time, a great increase is observed in the number of certain floating cells, which are occasionally to be noticed in the first chyle, but which are very abundant in the fluid drawn from the glands, and from the lacteals that have passed through them; these are colourless, and, like most other cells, contain smaller particles within them; their average diameter is about 1-4600th of an inch. By the time that the chyle reaches the central receptacle, its power of coagulating has still further increased;

so that its resemblance to blood, except in regard to colour, is much stronger. The proportion of fibrin and albumen which it contains, is much greater than that which existed in the first chyle, whilst the amount of oily matter is less; hence it seems probable that the latter has been partly transformed into albumen.

223. There can be little doubt that the change which the chyle undergoes in its passage through the lacteals, is partly due to the influence of the living walls of these vessels, upon the fluid in contact with them ; and it is also probable that the colourless cells which float in the fluid, have a special power of converting the albumen into fibrin. Hence we see the necessity for the long delay of the chyle in this system of vessels; which is provided for, in the higher animals, by the convolution of the lacteals in the mesenteric glands; and in the lower, by the simple extension of the vessels themselves. It is probable that, by being brought into very close neighbourhood with the blood in these glands, some further change may be effected; although, as each fluid is contained in its own tubes, which do not communicate, there can be no proper intermixture.

224. From the receptacle into which the chyle, and a considerable proportion of the contents of the lymphatics, are delivered, a tube passes upwards in front of the spine (Fig. 111); and this tube, called the *thoracic duct*, conveys these nutritious fluids to the point where they are to be delivered into the current of blood. This delivery takes place at the angle where two veins unite,—a point at which there is less resistance than in any other part of their walls. These veins are the jugular, which brings the blood from the neck, and the subclavian, which conveys it from the arm, of the right side (Fig. 115); on the left side there is a smaller duct, which receives some of the lymphatics of the left side, and opens into the blood-vessels at a corresponding point between the left jugular and subclavian veins.

225. But there are animals which are not only destitute of lacteal and lymphatic vessels, but even of blood-vessels; and in these, as in the Cellular plants (VEGET. PHYS. §. 102), there is but little transmission of fluid from one part of the body to the other; for every portion, both of the internal surface (or lining

of the stomach), and of the external surface which is bathed in the surrounding fluid (for most of these animals are aquatic), seems equally to possess the power of absorption; and the parts to whose nourishment the fluid thus received into the body is to be appropriated, are in the immediate neighbourhood of those which have absorbed it. This is the case, for example, in the Hydra and Sea-Anemone; and, more or less, in all the Polypes; as well as in the inferior Entozoa, and in the (so-called) Polygastric Animalcules. Between these, therefore, and the Cellular Plants, a remarkable analogy exists in regard to the mode in which the nutriment is absorbed and applied; the difference being, that the Animal possesses a digestive cavity, lined by an inward extension of the external surface, which does not exist in Plants (§. 11). And it is upon the walls of this cavity, that the absorbent vessels of Animals (whether lacteals or blood-vessels) are distributed, collecting the nourishment in contact with them; just as the roots of a Plant, spread through the soil, draw up that which it contains. Moreover we have seen, even in Plants, an occasional approach to this peculiarity of Animals; the pitcher of *Dischidia*, with its tuft of rootlets, bearing no inconsiderable resemblance to a digestive cavity or stomach (VEGET. PHYS., §. 245). There is a further analogy between the two kingdoms, in the manner in which absorption of fluid takes place by the *general* surface, when the usual supply is deficient. (Compare §. 220, and VEGET. PHYS. §. 271).

CHAPTER V.

OF THE BLOOD, AND ITS CIRCULATION.

226. The processes that have been already explained, have for their object to prepare a nutritious fluid, which supplies the materials for the growth of the several parts of the body, and which is conveyed through them by the apparatus to be presently described. In Man and the higher animals, this fluid, which is known as the *Blood*, has a red colour, and contains a large quantity of solid matter. The *redness* of the blood has been mentioned as a distinctive character of the Vertebrated classes (§. 68); it exists in Mammalia, Birds, Reptiles, and Fishes, and in these alone. In the Molluscous classes, as in Insects, Crustacea, and Zoophytes, the nutritious fluid is nearly colourless; and it will hereafter appear that this fluid bears, in some respects, a stronger resemblance to the chyle and lymph of Vertebrata, than to their blood (§. 235). There is an apparent exception in the case of certain marine Worms, whose circulating fluid has a reddish hue; this does not depend, however, upon the presence of any of the *red particles*, which are characteristic of the blood of Vertebrata (§. 229); but upon a reddish tinge in the fluid itself.

227. The blood exists, however, in two different states in every animal. When it is drawn from a slight scratch or other wound of the skin, it is of a bright red hue; whilst that which is drawn in bleeding from the arm, is of a dark purple. The former is termed *arterial* blood, because it is, for the most part, contained in the tubes which are called arteries, and which are conveying it from the heart to the tissues it has to nourish. The latter is called *venous* blood, because it is drawn from the veins, by which

it is returned from the tissues to the heart, after having performed its part in them. Hence it is evident that this change of character has been produced, during the passage of the blood through the tissues; and so important is the alteration, that the blood which has been subjected to it is not fit to pass again into the arteries of the body, until it has been renewed by exposure to air in the lungs. In *their* vessels, the contrary change—of which the nature will be presently explained (§. 253)—is effected; and the dark hue of venous blood gives place to the bright red of the arterial fluid, which is again changed during the passage of the blood through the body, to be again restored in the lungs.

228. Hence the continual movement of the blood is necessary for two purposes in particular;—*first*, to convey the nutritive materials from the place where they are received and prepared, to that where they are appropriated, and thus to afford to every organ a constant supply of the materials which it requires;—and, *second*, to carry this fluid, at regular intervals, to a certain part of the body, where it may be exposed to the influence of the air, so as to regain the qualities it has lost, and part with what it has taken up to its prejudice. But there are many other objects fulfilled by it, which will unfold themselves as we proceed.

Properties of the Blood.

229. When the circulating blood of a *red-blooded* animal is examined with a microscope, it is seen to consist of two distinct parts;—a clear and nearly colourless fluid, to which the name of *liquor sanguinis* (or liquor of the blood) is given;—and of an immense number of rounded particles floating in this fluid, which are commonly termed the *globules* of the blood. The shape and size of these particles are, for the most part, very uniform in animals of the same species; but in no instance are they globular; and it would be much better, therefore, to call them by some other name. In Man and most other MAMMALIA, they are nearly flat *discs*, resembling pieces of money, but usually exhibiting a slight depression towards the centre. No

very distinct central spot can be perceived in them, except that which results from the depression; and this may be made to disappear, by adding water to the liquid in which they are suspended; for the discs will first become flat, and will then bulge out on either side, at last swelling so as to burst. The reason of this will be presently explained. In MAN and the MAMMALIA in general, the diameter of these blood-discs varies from about 1-2800th to 1-4000th of an inch; but in the small *Musk-deer*, it is less than 1-12,000th. In the Camel tribe, the discs are oval, as in the lower Vertebrata.

FIG. 112.

BLOOD-DISCS IN MAN.

230. In Birds, Reptiles, and Fishes, the blood-particles present some curious differences from those of Mammalia. In the first place, they are much larger; their form, also, is oval instead of being round; and instead of being depressed in the centre, they bulge out on each side. This bulging is evidently occasioned by the presence of a *nucleus* or kernel, which is more solid than the rest. The long diameter of the oval disc of BIRDS varies from about 1-1700th to 1-2400th of an inch; and the short diameter from about 1-3000th to 1-4800th. Thus the discs, though much longer than those of Man, are not in general much broader. In REPTILES, there is considerable diversity as to the size of the discs; but the largest particles are found in the group of *Amphibia*, and especially in those species which retain their gills through life. The oval discs of *Frogs* have a long diameter of about 1-1000th of an inch; and a transverse diameter of about 1-1800th. Those of the *Proteus* and *Siren* (animals formed upon the same plan as the Axolotl, §. 97) can even be distinguished by the naked eye: those of the Siren have a long diameter of about 1-435th of an inch; and in the Proteus the long diameter is stated occasionally to reach 1-337th of an inch. In Fishes, also, the size of the blood-particles is variable; they are commonly, however, rather larger

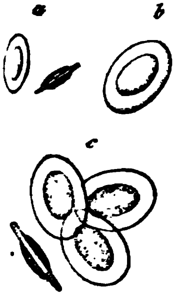

FIG. 113.

OVAL BLOOD-DISCS; *a*, FROM FOWL; *b*, FROM FROG; *c*, FROM SKATE.

than those of the Frog; but do not nearly approach those of the last-named remarkable animals.

231. It is by observing the large blood-discs of the Frog, and still better those of the Proteus and Siren, that we can obtain the best information as to their structure. They are evidently *flattened cells*, having an envelope or cell-wall, which consists of an extremely delicate membrane, and which contains a fluid. The *nucleus* consists of an assemblage of minute granules, which seem adherent to each other, and to the wall of the cell; and it corresponds, in all essential particulars, to the nucleus of the Vegetable cell (See VEGET. PHYS. §. 355), as well as to that of the cells in which the Animal tissues have their origin (CHAP. VII.). The fluid contained in the cells has a red colour; and it is to this that the peculiar hue of the blood of Vertebrata is owing. When we are looking at a single layer of blood-discs, their *red* colour is not apparent, but they have rather a yellowish tint; and it is only when we look through a number at once, that the characteristic hue is seen. Where the blood of Invertebrated animals has any characteristic tint, it is not due to that of the particles it contains, but to the *liquor sanguinis* itself.

232. The fluid contained in the blood-discs has dissolved in it a considerable quantity of iron; and the purpose of this appears to have a very important connection with the introduction of oxygen into the body. The fluid is of about the same density as that in which the particles float; and thus neither will have a tendency to pass towards the other. But, if we dilute the *liquor sanguinis* with water, the fluid outside the cells will have a tendency to pass towards their interior, according to the law of Endosmose (See VEGET. PHYS. §. 117). The cells will in consequence be first distended, and will then burst; and their contents will be diffused through the surrounding fluid, whilst their membranous walls will subside to the bottom. On the other hand, if the liquor sanguinis be rendered denser than the fluid in the blood-discs, as by the admixture of gum or syrup, the latter will pass towards it, and the cells will become still more flattened, and more or less completely emptied. Altera-

tions in the state of the blood-discs appear to take place in various diseases, in consequence of variations in the density of the liquor sanguinis; and these may become the causes of other important changes in the condition of the body. The flexibility and elasticity of the blood-discs are well seen, in watching (with a microscope) its flow through the minute vessels; for if one of them meets with an accidental obstruction to its progress, its form becomes accommodated to that of the space left for it to pass, and it makes its way through a very small aperture, recovering its usual form immediately afterwards.

233. The proportion of blood-particles to the whole mass of the blood, varies greatly in different animals, and even in different states of the same animal. It is greatest in those, which have the highest muscular vigour and activity; and which consume the largest quantity of oxygen by respiration; hence these particles are rather more numerous in the blood of Birds than in that of Mammalia; and far more abundant in these last, than in Reptiles or Fishes. Again, they are more numerous in Men of ruddy complexion, strong pulse, and active habits, than in those of pale skins, languid circulation, and comparatively feeble powers. Their average proportion in Man may be stated at 127 parts in 1000 of blood; but the decrease which occasionally presents itself in disease, is much more marked than the increase,—the proportion being sometimes as low as 27. When too abundant, they produce what is known as the *plethoric* condition of the body; in which hæmorrhage, from the bursting of a blood-vessel, is liable to occur. Their number is effectually reduced by bleeding; and the aspect of those who have suffered from extreme loss of blood, gives sufficient evidence that the deficiency is not made up for a long period. The most effectual assistance that can be given, in cases where the proportion of blood-particles is too low, is the administration of *iron* as a medicine; for this seems to have the power of hastening the re-production of the particles, being itself an essential ingredient of the fluid they contain; and there are facts which show its remarkable power of increasing their amount, in proportion to the mass of the blood. It appears that the blood-particles, like

other cells, have a certain allotted term of life; — that they are continually dying, but as continually reproducing themselves;— and that thus the requisite proportion is kept up. But if a large number have been withdrawn, their replacement must be a gradual process.

234. Physiologists are now generally agreed, that the function of the red particles is to convey *oxygen* from the lungs, to the tissues and organs through which the blood circulates; and to bring back the *carbonic acid* which is set free in these, so as to deliver it at the lungs. It appears probable that the iron they contain is in the state of *protoxide* (that is, combined with a single proportional of oxygen); which will readily unite, either with another proportional of oxygen (so as to become the *peroxide*), or with a proportional of carbonic acid, forming the *carbonate*. In the lungs, the blood-discs take in an additional quantity of oxygen, which they carry into the minute vessels, by which the blood is distributed to the body at large. The blood is there subservient to certain changes in the tissues; it affords them the nourishment they require, and receives from them the products of the continual decay which is taking place in them. In the course of these changes, the blood gives up its oxygen, and receives carbonic acid; its iron being probably converted from the condition of peroxide into that of carbonate, in which state it returns to the lungs. When exposed, in these organs, to the influence of the air, it gives off its carbonic acid, and receives a fresh supply of oxygen; this is again conveyed to every part of the body, and again replaced by carbonic acid, which is brought back to be thrown off at the lungs. Now it is in the *muscular* system that there is the greatest demand for oxygen; for it is not capable of vigorous action, unless this be supplied to it. The quantity it requires, however, depends upon the exercise of its powers; for when at rest, it wants little or no more than that which is made use of by the other tissues; but when in activity, it needs a greatly-increased supply. The quantity of oxygen which the animal takes in by its lungs, and the amount of carbonic acid which it gives off by the same channel, vary, therefore, with the muscular exertion it makes. This variation is most

easily observed and measured in Insects; and it is found in them to be enormous.

235. But, it may be objected, the blood of the Invertebrata does not contain these red particles, to which so important a function has been assigned; and how is the conveyance of oxygen to *their* tissues provided for? The reply is very simple. In *Insects*, and other ARTICULATA which have active powers of motion, the air is conveyed to the tissues, not through the medium of the blood, but *directly* through air-tubes which convey it to every part of the body (§. 320). And in the MOLLUSCOUS classes, as among the *Crustacea* also, the muscular system forms so small a part of the general mass of the body, and its movements are so sluggish, that the quantity of oxygen which the fluid part of the blood conveys to them, is sufficient for their need.—Besides the *red* particles of the blood, there are others which possess no colour, and which seem to have a function altogether different. Their size is pretty much the same in all Vertebrata, being usually about 1·3000th of an inch in diameter. In the blood of *Man* and the *Mammalia* in general, they are not easily distinguished from the red particles; since their size is so nearly the same; and the colour of single discs of the two kinds is not very dissimilar. But with a good microscope, several differences can be seen; and there is much reason to believe, that these colourless particles are the same with the particles of the chyle and lymph (§. 222). In the lower Vertebrata, whose blood has large oval red particles, the difference between the two kinds is very obvious; and the resemblance which the colourless globules bear to those of the chyle and lymph is very striking. Similar colourless particles exist, to a variable amount, in the nutritive fluid of Invertebrated animals; so that in this, as in some other respects, that fluid bears a stronger resemblance to the chyle and lymph of the Vertebrata, than it does to their blood, which is characterised by the presence of the red particles.

236. Of the properties of the *liquor sanguinis*, whilst it is circulating in the vessels, the microscope tells us nothing; since it constantly remains in the state of a transparent fluid. But when the blood is withdrawn from the living body, it soon

undergoes a very curious and important change. A large portion of it passes into the solid state, forming the *crassamentum* or clot; whilst there remains a transparent liquid of a yellowish hue, which is termed the *serum*. It is evident that the clot contains all the red particles; but it is also certain that this *coagulation* is not due to them; since the red particles, when separated from the rest of the blood, have no tendency whatever to adhere in this manner. When a very thin slice of the clot is examined with a microscope, it is found to be made up of a network of *fibres*, interlacing in every direction, and including the blood-discs in its meshes. These fibres are produced by the spontaneous change of the *fibrin* of the blood, from the fluid to the solid form. So long as the blood is circulating in the vessels of the living body, so long does its fibrin remain dissolved in the watery part of it; but so soon as it is withdrawn from these, and is allowed to remain at rest, it undergoes this remarkable change. If fresh-drawn blood be continually stirred with a stick or beaten with twigs, the fibrin coagulates in irregular strings, which adhere to the stick or twigs; and it does not then include the red particles, which are left behind in the fluid. In this manner it may be completely separated from the other elements of the blood, which have not in themselves the least tendency to coagulate spontaneously.

237. In certain conditions of the blood (generally resulting from disease), even when the coagulation is allowed to take place in the ordinary manner, the fibrin and the red particles separate from one another,—the latter sinking to the bottom, and the former being left at the surface; and the upper part of the clot is then nearly colourless, exhibiting what is commonly known as the *buffy coat* or crust; whilst the lower part of it includes the red particles, and has a very deep colour. The buffy coat, being composed almost exclusively of the fibrous network, is very firm in its texture, being sometimes almost leathery in its character; whilst the lower part of the clot, which is chiefly composed of the red particles, loosely bound together by scattered fibres, is very soft, and easily broken asunder. This effect may be also produced, by acting on healthy blood with certain substances

which retard its coagulation, such as a strong solution of Glauber's salt; for if sufficient time is allowed, the red particles will subside in consequence of their greater specific gravity, leaving a colourless layer of fibrin above them.

238. There is another experiment which fully proves that the coagulation is due to the fibrin alone, and that the red particles are not concerned in it. The blood of a Frog, or any animal having blood-discs sufficiently large, may be caused to pass through filtering-paper, which will retain and collect its blood-discs, allowing the *liquor sanguinis* to flow through it; and this fluid will coagulate just as completely, as if these particles were retained in it. It is this *liquor sanguinis*, or blood deprived of its red particles, which is poured out by the vessels, for the closing of wounds, and for the formation of new tissue. To the surgeon it is known under the name of *coagulable lymph;* and the uses of this substance in the repair of injuries has long been known. A general account of the process will be given hereafter (CHAP. VIII.).

239. We do not see the coagulation of the fibrin of the blood taking place whilst it is circulating in the vessels; and it is obvious that it could not occur without blocking them up, and preventing the flow of fluid through them. But there is good reason to believe, that the fibrin is being continually withdrawn from the blood by the solid parts through which it flows, and is converted by them into a regularly organised tissue like their own. The fibrous network which results from its *spontaneous* coagulation, is probably the lowest form of organisation; but there are several parts of the animal body which seem to have had their origin in this (CHAP. I.). The most important tissues are developed, however, from *cells*, analogous to those of Plants (see VEGET. PHYS. §. 71); and it appears to be in supplying the materials for their growth and reproduction, that the fibrin is chiefly required. There are few, if any, parts of the body which do not take their origin in this substance; and hence it has been not unaptly termed *liquid flesh.*

240. When the fibrin and the red particles have both been separated from the blood, there remains a fluid in which a good deal of animal matter is dissolved, together with several

saline compounds. This animal matter may be detected by *heat*, which causes the liquid to coagulate or *set;* but the clot has nothing in common with that formed by the spontaneous coagulation of the fibrin; for it seems composed of a mere assemblage of granular particles, crowded together without any definite arrangement. It is, in fact, composed of *albumen*, whose characteristic property it is (as already stated, §. 17) to coagulate by heat,—of which we have a familiar example in the hardening of the egg by boiling. Besides this albumen, the serum includes fatty matter, and other substances which have their several purposes in the animal economy; as well as saline matter, of which a considerable proportion is muriate of soda, or common salt. The proportion which the solid matter of the serum bears to the whole mass of blood, in health, is about 80 parts in 1000; and of these about 66 parts are albumen, and 10 parts saline matter.

241. There is no reason to think that albumen, as long as it remains in that state, is employed as the material for the formation of the animal tissues. But it is, as we have seen, the first nutritive ingredient which is formed by the process of digestion; and it may be regarded as the raw material out of which, by a process consisting of several stages, the animal tissues are manufactured. Of these stages, its conversion into fibrin is the first; and there seems good reason to believe that this conversion is effected, by the agency of those floating cells which are found in the chyle, and of the colourless particles of the blood which seem identical with these. For in various peculiar conditions of the body, the quantity of fibrin, which usually amounts to no more than about 3 parts in 1000, undergoes a great increase; and it is then found that the number of these cells in the blood has been augmented in a corresponding degree.* Thus the fibrin may be regarded as a transition-stage between albumen and organised tissue; just as, to use a homely comparison, the spun-yarn is the intermediate stage between the raw cotton and the woven calico.

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* See the Author's Report on the Physiology of Cells, in the British and Foreign Medical Review, January, 1843.

242. The influence of the blood upon the nutritive functions is easily proved. If, by mechanical means, as by tying the principal blood-vessel, we cause a permanent diminution, to any considerable extent, in the quantity of blood with which any organ is supplied, a decrease in its size is soon apparent, and it may even shrink almost to nothing. On the other hand, we observe that, the more active the function of a part, the larger is the quantity of blood with which it is supplied, and its own bulk undergoes an increase. The effect of the continual exercise of any muscular part, in augmenting its bulk, is well known; thus among dancers, the muscles of the leg, and especially those of the calf, acquire a great size; whilst among watermen, blacksmiths, coachmen, and others, who make great use of the muscles of their arms, these become much increased. This change in the quantity of blood sent to particular organs, is still more remarkable in the case of those which undergo a periodical or an occasional development. Thus, when the antlers of the Stag, which fall off every year, are being renewed, the arteries that supply the parts of the skull from which they spring, are greatly increased in size; but they shrink again, as soon as the growth of the horns is completed for that year. A similar increase takes place in animals that suckle their young, in the size of the arteries that supply the mammary glands, by which the milk is formed; and these also shrink, when this liquid is no longer required.

243. For the purposes of nutrition and secretion merely, the liquor sanguinis appears to be alone required in the higher animals, as in the lower; but the organs thus formed cannot be aroused to activity, unless they are supplied with oxygen, conveyed to them by the red particles. When an animal is bled largely, it is gradually weakened as the flow proceeds, and at last it seems to lose all consciousness and power of movement. If allowed to remain in this condition, it seldom or never recovers of itself. But if we inject into its veins, by small quantities at a time, blood similar to that which it has lost, the apparent corpse becomes as it were reanimated, and all its functions are completely re-established. The im-

portance of the red particles is manifestly seen in the effect of this remarkable operation, which is called the *transfusion* of blood; for if instead of blood, freshly obtained from another living animal, we inject serum without these particles, the effect is no greater than if so much water were introduced, and the animal dies of the hæmorrhage. By this operation, practised on the Human subject, many valuable lives have been saved, that would otherwise have been destroyed by loss of blood.

Circulation of the Blood.

244. In some of the lower tribes of Animals, the blood appears to circulate in channels, which are merely excavated in the substance of their tissues and organs. But among all the Vertebrata, and even in most of the Invertebrated classes, the movement of the blood takes place in a very complicated apparatus; which is composed, 1st, of a system of tubes or canals, which serve to convey it through every part of the structure; and, 2nd, of a special organ, for the purpose of giving motion to that liquid. These canals are known as the *blood-vessels;* and this special organ is the *heart.*

245. The *heart* is the centre of the circulating apparatus. It is a kind of fleshy bag, communicating with the blood-vessels: and it alternately dilates to receive the blood, which is conveyed to it by one set of these; and then, by contracting, forces it out into another set of tubes. In this manner a continual current is kept up. Almost all animals have a heart, or something which represents it. Such an organ exists, not merely among all the Vertebrated classes, but in all the Mollusca, and in the higher Articulata. But, as will presently appear, there is a great diversity in its form, and in the complexity of its construction; for whilst, in its simplest condition, it possesses but one cavity, communicating with both sets of vessels,—it contains, in its highest forms, four different chambers, each of which has its own peculiar function.

246. The two sets of blood-vessels just adverted to are, 1st, the *arteries*, which convey the blood from the heart into the

several parts and organs of the body; and, 2nd, the *veins*, which collect the blood that has been distributed through these, and return it to the heart. The Arterial system, as it issues from the heart, consists of one or more large trunks, which divide into branches, very much in the manner of the *stem* of a tree; these branches again subdivide into others more numerous but smaller, and these again into twigs still more numerous and more minute; until almost every portion of the body is so penetrated with them, that not even a trifling scratch, cut, or prick, can be made, without wounding some one of these small divisions.—The Venous system presents a corresponding distribution, but it is destined for an opposite purpose; and we must regard it as commencing in the tissues, by the minute canals, which run together like the little rivulets that form the origin of a mighty river, or like the smallest fibres of which the *roots* of a tree are made up. These larger canals gradually unite with each other as they approach the heart, towards which they all tend; just as the various tributary streams pour their contents into one principal channel: and at last all the veins empty into the heart, by one or two large trunks, the blood which they have conveyed from the several parts of the body; just as all the tributaries, which have arisen over a wide extent of country, pour into the ocean the water they have collected, by one mouth which is thus common to all of them.

247. Although the *number* of the Arterial branches increases so vastly, as we proceed from their origin towards their termination, yet their *capacity* does not, at least in any considerable degree;—that is, the first or main trunk will allow as much fluid to pass through it in a certain time, as will the whole of the first set of branches into which it divides, or the still more numerous subordinate branches, into which these diverge. Or, to put this fact in another form, if we cut across the main trunk, and compare the *area*, or space included within its circular walls, with the sum of the areas of all the branches it supplies at a certain distance—say a foot—from the heart, we shall find them precisely equal; and the same will hold good, if the comparison is made with the sum of the areas of the more numerous but

smaller branches at a greater distance from the main trunk. It is quite true that, when an artery divides into branches, the combined size of these *seems* to be greater than that of the trunk; but this is only because the comparison is made, not between the *areas* of their circles, but their *diameters*.* Thus, an artery of $10\frac{1}{10}$ lines in diameter, may divide into three branches, *two* of them having a diameter of 7 lines, and the *third* a diameter of 2 lines;—and yet these will convey no more blood than the single trunk. For, according to a simple rule in geometry, the *areas* of circles are to each other as the squares of their diameters. The area of the trunk is expressed, therefore, by the square of $10\frac{1}{10}$, which is almost exactly 102. The areas of the two large branches, in like manner, are expressed by the number 49, which is the square of 7; and that of the smaller one by 4, the square of 2; and the sum of these $(49+49+4)$ is exactly 102, making the combined areas of the branches the same as that of the trunk. In like manner, one of the branches of 7 lines diameter might subdivide into two branches of a little less than 5 lines each; for, as the square of 5 is 25, and twice that number is equal to 50, the combined areas of two branches of 5 lines each, exceed by very little the area of the trunk of 7 lines.—Hence it results, that the pressure of the blood upon the walls of the arteries will be everywhere the same;—a conclusion which is confirmed by experiment. This will be easily understood, by referring to the Treatise on Hydrostatics.

248. There are certain differences in the structure and distribution of the Arteries and Veins, which it is desirable to mention. The Arteries receive the blood pressed out from the heart, and must be strong enough to resist the force of its contraction; otherwise, as there is a considerable impediment to its onward flow, produced by the minuteness of the tubes through which it has to pass, and the friction to which it is subjected against their sides, their walls would give way, and they would burst. They have, accordingly, a tough elastic fibrous coat, which bears great resemblance to muscle in structure and properties. On

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* It is a common but erroneous statement in Physiological works, that the size of the arterial system increases at each subdivision.

the other hand, the Veins receive the blood after the heart's power over it has been almost expended; and when it is consequently moving much more slowly. They are very large in proportion to the arteries; so that, if we were to cut across a limb at any place, and to estimate the respective areas of all the veins and arteries, we should find that of the veins two or three times as great as that of the arteries. Hence the pressure on their walls is much less; and their strength does not require to be so great. Accordingly, we find their walls much thinner, and the tough elastic fibrous coat almost entirely wanting.

249. The difference in the force with which the blood presses on the walls of the arteries and veins, is seen when these vessels are wounded. If a small incision be made into an artery, the blood spouts from it to a great distance; but if a similar incision be made in a vein, the blood merely flows out, unless we stop its passage to the heart, by making pressure on the vein above the orifice, as in ordinary blood-letting (§.277). Hence much greater pressure is requisite to check bleeding from an artery than bleeding from a vein; and it frequently happens that no amount of pressure can prevent the continued drain of blood from the former, so that it becomes necessary to stop the flow of blood through the artery altogether, by tying a ligature tightly round it.

250. The Arteries are for the most part so distributed, that their trunks lie at a considerable distance from the surface of the body, so as to be secluded from injury; and they are often specially protected by particular arrangements of the bony parts. Of the Veins, on the other hand, a large proportion lie near the surface, and they are consequently more liable to be injured; but, for the reason just stated, wounds in them are of comparatively little consequence.

251. The ultimate ramifications of the Arteries are continuous with the commencing twigs of the Venous system. The communication is established by means of a set of extremely minute vessels, which are termed *capillaries*.* These capillaries form

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* From the Latin *capilla*, hair; so named on account of their being, like hairs, of very minute size. Their diameter is really, however, far *less* than that of ordinary hairs.

a network, which is to be found in almost every part of the body. It is in them alone that the blood ministers to the operations of nutrition and secretion. Even the walls of the blood-vessels are incapable of directly imbibing nourishment from the blood which passes through them; but are supplied with minute branches, which proceed from neighbouring trunks, and form a capillary network in their substance. The diameter of the capillaries must of course bear a certain proportion to that of the blood-discs which have to pass through them. In Man they are commonly from about 1-2500th to 1-1600th of an inch in diameter. In the *true* capillaries, it would seem that only one row or file of these particles can pass at a time; but we frequently see vessels passing across from the arteries to the veins, which will admit several rows. There seems, however, to be a considerable difference in the diameter of the same capillary at different times; a change sometimes taking place from causes which are not yet understood. This system of capillary vessels evidently bears a strong resemblance to that of the *laticiferous* vessels of Plants (See VEGET. PHYS. §. 87); but in the latter, there are no large trunks, because there is no central organ of impulsion corresponding to the heart of Animals, and the circulation is entirely capillary.

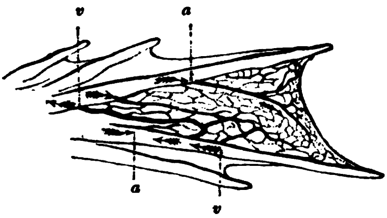

FIG. 114.—CAPILLARIES IN THE WEB OF THE FROG'S FOOT; *a*, ARTERIES, *v*, VEINS.

252. The Arterial and Venous systems thus communicate with each other at their opposite extremities;—their large trunks through the medium of the heart;—and their ultimate subdivisions through the capillaries. Hence we may consider this double apparatus of vessels as forming a complete *circle*, through which the blood flows in an uninterrupted stream, returning continually to its point of departure; and the term *circulation* is therefore strictly applicable.

253. But the conveyance of the nutritive fluid to the several

organs of the body, for their support and maintenance, is not the only object to which its circulation has to minister. It is requisite that the blood should be continually exposed to the influence of the air, by which it may get rid of the carbonic acid with which it has become charged during its circulation in the system, and may take in a fresh supply of oxygen, which has been withdrawn from it at the same time. In order to effect this exposure, the blood is conveyed to a particular organ, in which it is made to pass through a set of capillary vessels; and is there brought into almost immediate contact with air. In the lower tribes, in which this *aeration* is (from various causes hereafter to be explained) much less constantly necessary than in the higher, we find the respiratory organ supplied by a branch from the general circulation; and the blood which has passed through it, and which has been subjected to the invigorating influence of the air, is mingled in the heart with that which has been deteriorated by circulating through the system, which is again supplied with this mixed, half-aerated blood. But in the highest classes, there is a distinct circle of vessels, subservient to the respiratory function: an arterial trunk issuing directly from the heart, and subdividing into branches which terminate in the capillary system of the respiratory organ; a set of capillaries, in which the aeration of the blood takes place; and a system of veins, which collects the blood from these, and returns it to the heart. This circuit of the blood is sometimes called the *lesser circulation*; to distinguish it from that which it makes through the general system, which is called the *greater circulation*.

254. But the course which the blood takes, and the structure of the apparatus which is subservient to its movement, differ very greatly in the several classes of animals. The chief of these differences will be pointed out hereafter; and it will be preferable to commence with the highest and most complex form of the circulating system, such as we find in Man, that it may serve as a standard of comparison, with which these may be contrasted.

Circulating Apparatus of the Higher Animals.

255. In Man, and those animals which approach him most nearly in structure, the *heart* is situated between the lungs in the cavity of the chest, which is termed by anatomists the *thorax.* Its form is somewhat conical; the lower extremity tapering almost to a point, and the upper part being much larger. The lower end is quite unattached, and points rather forwards and to the left; during the contraction of the heart, it is tilted forwards, and strikes against the walls of the chest, between (in Man) the fifth and sixth ribs. It is from the large or upper extremity, that the great vessels arise; and these, being attached to the neighbouring parts, serve to suspend the heart, as it were, in a cavity in which its movements may take place freely. This cavity is lined by a smooth serous membrane, which, near its top, is *reflected* downwards over the vessels, and covers the whole outer surface of the heart. Hence as the surface of the heart, and the lining of the cavity in which it works, are alike smooth, and are kept moist (in health) with a fluid secreted for the purpose, there is as little interruption as possible from friction, in the working of this important machine.

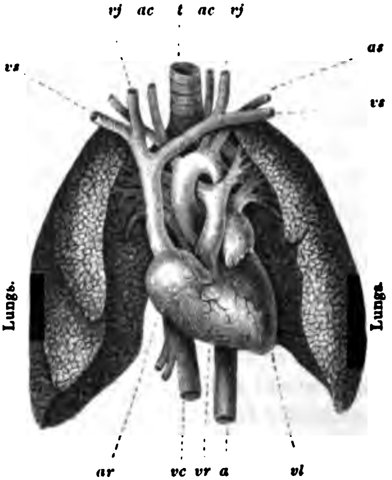

FIG. 115.—LUNGS, HEART, AND PRINCIPAL VESSELS OF MAN.

ar, right auricle; *vr*, right ventricle; *vl*, left ventricle; *a*, aorta; *vc*, vena cava; *ac*, carotid arteries; *vj*, jugular veins; *as*, subclavian artery; *vs*, subclavian veins; *t*, trachea.

256. We may stop to explain the mode in which this *pericardium* (or membrane surrounding the heart) is disposed; be-

cause it affords a simple type or specimen of the mode in which other membranes of similar character are arranged round other organs, such as the lungs, bowels, and brain, and also in the joints. In Fig. 116 is seen the heart suspended freely in its cavity, by the large vessels proceeding from its top. This cavity is completely lined by the membrane *p'*, which closely embraces the vessels, and which then bends down over the surface of the heart, so as to enclose it in the envelope, *p*. Hence it will be seen that the membrane forms a completely *closed bag* or *sac;* whilst it nevertheless includes the heart, and allows it to communicate with its vessels. To adopt a homely simile, it is exactly analogous to a common double cotton or woollen nightcap; for this too is composed of a closed bag; and the head is really on the *outside* of its cavity (which intervenes between its two layers), whilst seeming to be included within it. It is by a similar arrangement, that the other organs just mentioned are kept in their places; and thus their vessels, nerves, &c. are allowed to reach them, without *perforating* their envelope; whilst they are securely retained in their places, in a mode which nevertheless permits sufficient freedom of movement.

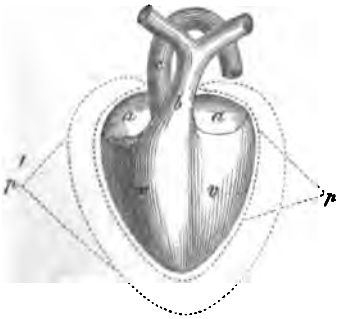

FIG. 116.—DIAGRAM OF THE PERICARDIUM.

aa, auricles; *vv*, ventricles; *b*, pulmonary artery; *c*, aorta; *pp'*, pericardium.

257. The heart may be described as a hollow muscle, which, in Birds and Mammalia, as in Man, is divided into four distinct chambers. This division is effected by a strong *vertical* partition, that divides the entire heart into two halves, which are almost exactly similar to each other, excepting in the greater thickness of the walls on the left side; and each of these halves (which do not communicate with one another) is again subdivided by a transverse partition, into two cavities, of which the upper one is termed the *auricle*, and the lower the *ventricle*. Thus we

have the right and left auricles, and the right and left ventricles. Each auricle communicates with its corresponding ventricle, by an aperture in the transverse partition, which is guarded by a valve. The walls of the ventricles are much thicker than those of the auricles; and for this evident reason,—that the ventricles have to propel the blood, by their contraction, through a system of remote vessels; whilst the auricles have only to transmit the fluid that has been poured into them by the veins, into the ventricles, which dilate themselves to receive it. The comparative thickness of the walls of the left and right ventricles is explainable on the same principle; for the left ventricle has to send the blood, by its contractile power, through the remotest parts of the body; whilst the right has only to transmit it through the lungs, which, being much nearer, require a far less amount of force for the circulation of the blood through them.

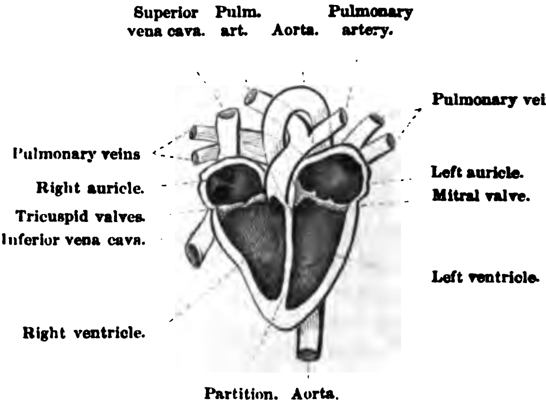

FIG. 117.—IDEAL SECTION OF THE HUMAN HEART.

258. The *arterial* system of the greater circulation entirely springs from one large trunk, which is called the *aorta* (see Figs. 115—118); this originates in the left ventricle, and is the only vessel which passes out from that cavity. It first ascends towards the bottom of the neck; then forms what is termed the *arch*, a sudden curve, which gives it a downward direction; and

then descends along the front of the spinal column, behind the heart, as far as the lower part of the trunk, where it divides into two great branches, which proceed to the lower extremities. From the arch of the aorta are given off the vessels which supply

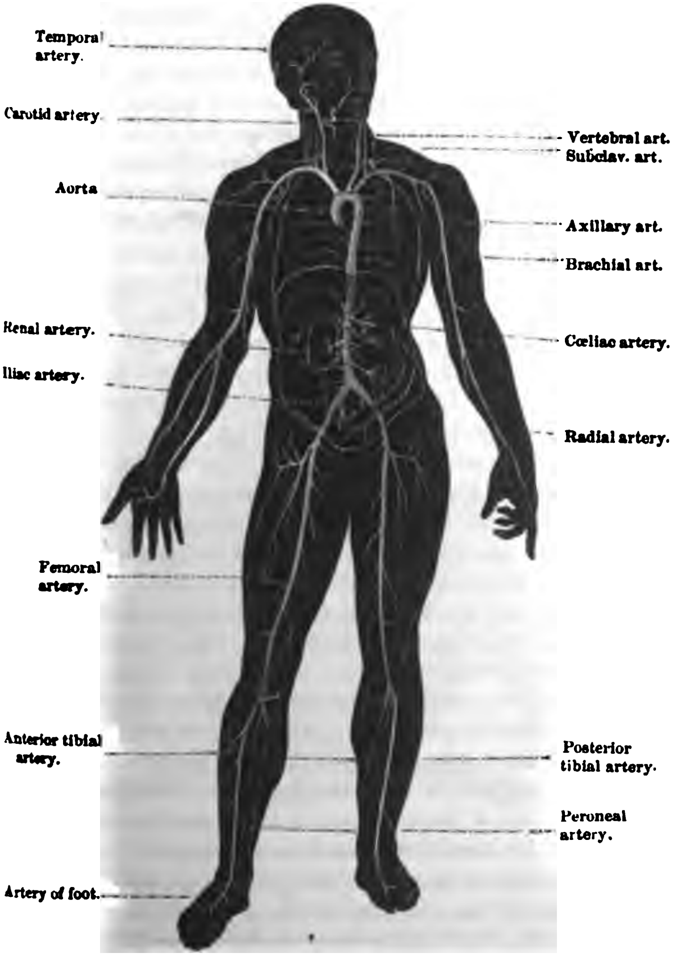

Fig. 118.—Arterial System of Man.

the head and upper extremities. These are, the two *carotids*, which ascend on either side of the neck; and the two *subclavian*, which pass outwards beneath the clavicles, so as to arrive at the arms,—becoming successively in their course the *axillary* and *brachial* arteries, as they pass through the axilla or arm-pit, and along the arm. The subclavian and carotid arteries of the right side arise together from the aorta, in Man, by a common trunk; but this arrangement varies much in different Mammalia. Thus in the Elephant, the two carotids arise by a common trunk,—the two subclavians separately. In some of the Whale tribe, all four are separate. In the Bat, the subclavian and carotid of the left side arise from a common trunk, like those of the right. And in those Ruminating animals which possess a long neck, all four arteries come off from the aorta together, by a large trunk, which first gives off the subclavians on either side, and then divides into the carotids. *All these varieties occasionally present themselves in Man;*—a fact of no small interest.

259. The *descending aorta*, in its progress along the trunk, gives off several important branches;—as the *cœliac*, from which the stomach, liver, and spleen are supplied; the *renal*, to the kidneys; and the *mesenteric*, to the intestines. It divides at last into the two *iliac* arteries; which, after giving off branches for the supply of the lower bowels, pass into the thighs, where they become the *femoral* arteries; and these again subdivide into branches for the supply of the leg.

260. For the sake of comparison, a figure of the arterial system of a Bird is introduced; from which it will be seen that by far the larger proportion of its blood is distributed to the upper extremities. In Man, the descending aorta is evidently the continuation of the aortic arch; and the parts which it supplies receive far more blood than the head and upper extremities, —the locomotion of *biped* man being performed, almost entirely, by his lower limbs. In *quadrupeds*, which require nearly as much strength in their fore feet as in their hind, the subclavian arteries bear a larger proportion to the iliac. But in *birds*, the function of locomotion is almost entirely performed by the wings; and their powerful muscles, which constitute the mass of flesh

lying on the breast, are supplied with blood by the arteries of the upper extremities, which here possess a manifest predominance. The aorta, soon after its origin, subdivides into three large branches; of which the two first, one on either side, (each giving off the subclavian and carotid arteries,) convey the blood to the head, the wings, and the muscles lying on the thorax; whilst the middle one curves backwards and downwards, and becomes the descending aorta. Now that which is here the continuation of the great side branch, is neither the carotid nor the subcla-

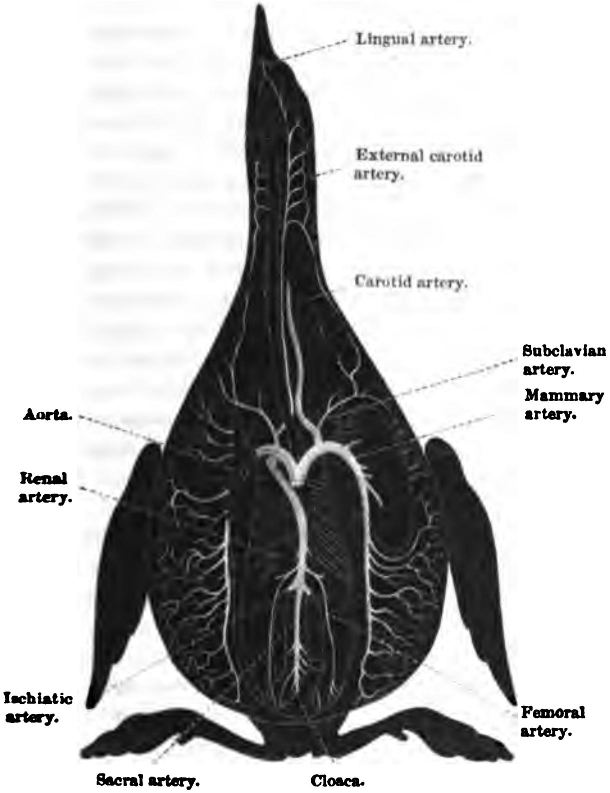

FIG. 119.—ARTERIAL SYSTEM OF BIRD.

vian, both of which are subordinate branches given off from it; but it is the trunk which distributes the blood to the muscles of the breast, and which in Man is a subordinate branch of the subclavian artery (the mammary). The descending aorta is seen to lose itself almost entirely in supplying the viscera of the trunk; so that the branches into which it divides at last for the supply of the legs are very small. These limbs, in birds, are usually required only for the support of the body at times of rest, and are seldom much concerned in locomotion; so that they possess little muscular power, and require but a small supply of blood.

261. It is very interesting to trace such differences in the arrangement of the vascular system, corresponding with variations in the general plan of structure, yet not exhibiting any actual departure from the general type. Thus, there is probably not a single large artery in Man, to which a corresponding branch might not be found in the Bird; on the other hand, there is perhaps not a single large artery in the Bird, to which there is not an analogous branch in Man. The chief difference consists in the relative sizes of the several trunks; and these correspond closely with the amount of tissue they have respectively to supply. Here then, we have one example, out of many that might be adverted to, of that Unity of Design, which we see everywhere prevalent throughout nature; manifesting itself in the close conformity of a great number of apparently different structures, to one general plan; whilst there is, at the same time, an almost infinite variety in the details.

262. There is a very interesting peculiarity in the distribution of the arteries, by which the due circulation of blood is provided for, even though there should be an obstruction in the main trunk. The branches which are given off from it at different parts, have frequent communications or *anastomoses* with each other; so that blood may pass from an upper part of a main artery into the lower, by means of these lateral communications, even though its flow through the trunk itself should be completely stopped. These anastomoses are very numerous in the arteries of the limbs, and particularly about the joints; and it is well that they are so; for, by relying on the maintenance of the

circulation through them, the Surgeon is often able to save a limb or even a life, which would otherwise be sacrificed.

263. Arteries are liable to a peculiar disease, termed *aneurism*, which consists in a thinning away, or rupture, of the tough fibrous coat, and a great dilatation of the other coats, so that a pulsating tumour is formed. This change takes place most frequently at the bend of the thigh, the ham, the shoulder, and the elbow; where the artery, in the working of these joints, often has to undergo sudden twists. The result of the disease would be generally fatal; in consequence of the gradual thinning away of the walls of the tumour, which at last bursts, allowing the blood to escape from the arterial trunk with such rapidity as, if unchecked, to cause almost instantaneous death. In order to prevent this, the surgeon *ties* the artery at some little distance above the aneurism,—that is, he puts a thread round it, which is drawn so tight as to prevent the passage of any blood to the aneurism. The circulation in the lower part of the limb is at first retarded; its temperature falls; and it becomes more or less insensible. But after the lapse of a few hours, the circulation becomes quite vigorous, the pulsations strong, the temperature rises, and the numbness passes off; and as the main trunk still continues completely obstructed, this can only be effected by the flow of blood through the anastomoses, which must in that short period have undergone considerable enlargement. Examination of the vessels after death shows that this has been actually the case. Even the aorta has thus been tied in dogs, without causing death; the anastomoses of the branches given off from its upper part, with those proceeding from the lower, being sufficient to maintain the circulation in the latter, when the current through the main trunk is obstructed: the operation has been twice performed on Man, as a last resource, in cases which would otherwise have been necessarily fatal,—unfortunately, however, without success.

264. A very complex series of anastomoses, forming a complete net-work of large tubes, is found in several situations, where it is desirable to retard the flow of blood to a particular organ, whilst a large amount is to be allowed to pass through. Thus in animals which keep their heads near the ground for

some time together, as in grazing, the arteries which supply the brain, suddenly divide, on their entrance within the skull, into a great number of branches, by the anastomoses of which, a complex network is formed; and from this network, by the reunion of its small vessels, originate the trunks which supply the brain in the usual manner. The object of this apparatus appears to be, to prevent the influence of gravitation from causing a too great rush of blood towards the brain, when the head is in a depending position; for the rapidity of its flow will be checked, as soon as it enters the network, and is distributed through its numerous canals. A similar conformation is found in the blood-vessels of the limbs of the Sloth, and of some other animals which resemble that animal in the sluggishness of their movements; and its object is probably to prevent the muscles from receiving too rapid a supply of blood, which would give them what (for these animals) would be an undue energy of action; whilst, by the very same delay, their power of acting is greatly prolonged,—as we find it to be in Reptiles, whose circulation is languid (§. 284).

265. In the Whale tribe, and some other diving animals that breathe air, we find a curious distribution of the blood-vessels which has reference to their peculiar habits. The *intercostal* arteries (which are sent off from the aorta to the spaces between the ribs on each side) are enormously dilated, and are twisted into thousands of convolutions, which are bound together into a mass by elastic tissue. This mass, which is of considerable bulk, lies at the back of the chest, along both sides of the vertebral column; and it serves as a reservoir, in which a great quantity of arterial blood may be retained. The veins also have very large dilatations, which are capable of being distended, so as to hold a considerable amount of venous blood; and thus, while the animal is prevented from breathing, by its submersion in the water, the circulation through the capillaries of the system is kept up, by the passage of the blood stored up (as it were) in the arterial system, into the venous reservoirs. If this provision did not exist, the whole circulation would come to a stand, in consequence of the obstruction it meets with in the lungs, when the breathing is stopped.

266. As to the *venous system* there is little to be added to what has been already stated, of its general character and distribution. The large proportion which its capacity bears to that of the arterial system, is shown by the fact, that every main artery is accompanied by a vein (frequently by two) considerably larger than itself; and that the superficial veins, which lie just beneath the skin, are capable of conveying at least as much more. The veins of the body in general unite into two large trunks, the *superior* and *inferior vena cava;* which meet as they enter the right auricle of the heart. The superior vena cava is formed by the union of the veins which return the blood from the neck (the *jugulars*) with those which convey it from the arms, (the *subclavian*) as shown in Fig. 115; and the inferior cava, (*v c* Fig. 115) receives the blood from the trunk, the organs contained in the abdomen, and the lower extremities.—There is an important peculiarity in the distribution of the veins of the intestines, which should not pass unnoticed. Instead of delivering their blood at once into the inferior vena cava, these veins unite into a trunk, called the *vena portæ,** which enters the liver and subdivides into branches, whence a capillary network proceeds that permeates the whole of its mass. It is from the venous blood, as it traverses this network, that the secretion of bile is formed; and the blood which is brought by the hepatic *artery* serves chiefly to nourish the liver,—no bile being formed from it, until it has become venous. The blood is carried off from this double set of capillaries by the *hepatic vein,* which carries it into the inferior vena cava. In Fishes, not only the blood of the intestines, but that of the tail and posterior part of the body, enters this portal system, which is distributed to the kidneys as well as to the liver. Thus all the blood which flows through the portal system, has to go through two sets of capillaries, between each period of its leaving the heart by the aorta, and its return to it by the vena cava.

267. We have yet to notice the *lesser circulation,* which is confined to the lungs only. The venous blood which is returned

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* The name *vein of the gate,* which this trunk has received, was given to it from the sort of gateway formed by the fissure of the liver into which it enters, guarded, as it were, by pillars before and behind.

to the heart by the venæ cavæ, enters the right auricle, and thence passes into the right ventricle. By the contraction of this last cavity, it is expelled through the pulmonary artery (Fig. 117), which soon divides into two main trunks that proceed to the right and left lungs respectively. The right trunk again subdivides into three principal branches, which are distributed to the three lobes or divisions of the right lung; whilst the left divides into two branches, which are in like manner distributed to the two lobes of the left lung. The capillaries, into which these branches ultimately subdivide, are distributed upon the walls of the air-cells; and the character of the blood is in them converted, by exposure to the air, from the dark venous to the bright arterial. From this capillary network the pulmonary veins arise; and the branches of these unite into trunks, of which two proceed from each lung, to empty themselves into the left auricle (Fig. 117). This auricle delivers the blood, now arterialised, or aerated (§. 253), into the left ventricle, whence the aorta arises; and by the contraction of this cavity, it is delivered through that vessel to the system at large.

268. It will be observed that the vessel which proceeds from the heart to the lungs is called the pulmonary *artery*, although it carries dark or venous blood. This is because it conveys the blood *from* the heart towards the capillaries. And, for a similar reason, the vessels which return the blood from the capillaries to the heart are termed pulmonary *veins*, although they carry red or arterial blood.

Mechanism of the Circulation.

269. The mechanical action, by which the blood is caused to circulate in the vessels, is easily comprehended. The cavities of the heart, as already explained (§. 245), contract and dilate alternately, by the alternate shortening and relaxation of the muscular fibres that form their walls (Chap. XII.); and the force of their contraction is sufficient to propel the blood through the vessels which proceed from them. The two ventricles contract at the same moment; the auricles contract during the relaxation of the ventricles, and are themselves relaxed whilst the ventricles

are contracting. The series of movements is therefore as follows:—The auricles being full of blood which they have received from the venæ cavæ and pulmonary veins, discharge it by their contraction into the ventricles, which have just before emptied themselves into the aorta and pulmonary artery, and which now dilate to receive it. When filled by the contraction of the auricles, these contract in their turn, so as to propel their blood into the great vessels proceeding from them; and whilst they are doing this, the auricles again dilate to receive the blood from the venous system, after which the whole process goes on as before. It is when the ventricles contract, that we feel the *beat* of the heart, which is caused by the striking of its lower extremity against the walls of the chest; and it is by the same action that the pulse in the arteries is produced (§. 276).

270. The combined actions of each auricle and its ventricle, may be illustrated by an apparatus like that represented in Fig. 120. It consists of two pumps, *a* and *b*, of which the pistons move up and down alternately; and these are connected with a pipe, *c f*, in which there are two valves, *d* and *e*, opening in the direction of the arrow. The portion *c* of the pipe represents the venous trunk, by which the blood enters the heart; the pump *a* represents the auricle, and the raising of its piston enables the fluid to enter and fill it. When its piston is lowered, its fluid is forced through the valve *d* into the pump *b* (which represents the ventricle), whose piston is at the same time raised to receive it; and when this piston is lowered in its turn, the fluid (being prevented from returning into *a*, by the closure of the valve *d*) is propelled through the valve *e* into the pipe *f*, which may represent an arterial tube; whilst at the same time a fresh supply of blood is received into the pump *a* by the raising of *its* piston.

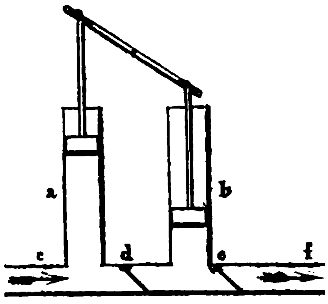

Fig. 120.

271. The number of contractions of the heart, which ordinarily takes place in an adult man, is from 60 to 70 per minute. It is usually rather greater in women; and in children it is far higher, being from 130 to 140 in the new-born infant, and gradually diminishing, during the period of infancy and childhood. It is rather greater in the standing position than in the sitting posture; and in sitting, than in lying down. It is increased by exercise, especially by ascending a steep hill, or going up stairs; and also by any mental emotion. It is important to remember these facts, in reference to the management of those who are suffering under diseases of the lungs, which prevent the ready passage of the blood through them; for if the heart's action be increased in strength and frequency, whilst the passage of the blood through the lungs is impeded, a feeling of very great distress is experienced; and there may be even danger of rupture of the heart or large vessels, or of sudden cessation of the heart's action, causing instant death. Such persons ought, therefore, carefully to refrain from any violent muscular movement, and also to avoid giving way to strong mental emotions.—In *syncope* or fainting, the heart's action is so weakened as to be scarcely perceptible, though it does not entirely cease; and this state may be brought on by several causes which make a strong impression on the nervous system, such as violent mental emotion (either joy, or grief, or terror), sudden loss of blood, and the like.

272. The blood which has been received by each ventricle from its auricle, is prevented from being driven back into the latter, on the contraction of the former, by a *valve* that guards the aperture through which it entered. This valve consists of a membranous fold, surrounding the borders of the aperture, and so connected with the surrounding parts, as to yield when the blood passes from the auricle into the ventricle, but to be tightened so as completely to close the aperture, when it presses in the contrary direction. The manner in which these valves act will be seen from Fig. 121, which is a section of the right auricle with its ventricle. The auricle, *a*, receives its blood from the two venæ cavæ, *e*, *e*; and transmits it into the ventricle, *b*, by the orifice, *c*. On each side of this orifice are seen

the two membranous folds, which are kept in their places by the tendinous cords, *d*. Now when the blood is passing from *a* to *b*, these folds yield to the current; but when the cavity *b* is filled and begins to contract, the blood presses against their under sides, so as to make them close against each other, so far as they are permitted to do by the tendinous cords. In this manner, the aperture is completely shut, and no blood can flow back. A valve of this kind exists on each side of the heart; but there is a slight difference between the forms of the two, whence they have received different names. That on the *right* side has three pointed divisions, to which the tendinous cords are attached; and it is hence called the *tricuspid* valve; whilst that on the *left* side has only two, so as to bear some resemblance to a bishop's mitre, whence it is called the *mitral* valve.

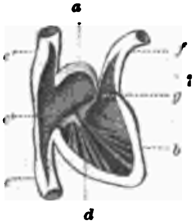

FIG. 121.—SECTION OF ONE SIDE OF THE HEART.

273. The aorta and pulmonary artery are in like manner furnished with valves, which prevent the blood that has been forced into them by the contraction of the ventricles, from returning into those cavities when they begin to dilate again. These valves, however, are formed upon a different plan, and more resemble those of the veins, which will be presently described. They consist of three little pocket-shaped folds of the lining membrane of these arteries (similar to those at *b b*, Fig. 122), which are pressed flat against the walls of those tubes, when the blood is forced into them; but as soon as they are filled, and the ventricles begin to dilate, so that the blood has a tendency to return, it presses upon the *upper* side of these pockets, and fills them out against one another, in such a manner as completely to close the entrance into the ventricle. The three little pocket-shaped folds, however, would not close the *centre* of the aperture, were it not that each of them has a little projection from its most prominent part, which meets with those of the others, and effects the requisite end. The situation of these valves (which are

termed *semilunar* from their half-moon shape) is seen at *g*, Fig. 121; where *f* is the pulmonary artery.

274. From the mode in which the blood is forced into the arterial system, by a series of interrupted impulses, it might be supposed that its course would be a succession of distinct jets; but this is prevented, and the current is reduced to an equable stream by the time it reaches the capillaries, through the elasticity of the walls of the arteries. In order to comprehend how this acts, we may first suppose a forcing-pump to be attached to one end of a long metal pipe, and to throw into it a series of interrupted jets; now as the walls of the pipe are hard and unyielding, it cannot contain more fluid at one time than at another, and consequently whatever amount of water is forced into it by the pump at one end, the same must be immediately discharged from the other. Hence this discharge must take place in a series of jets, exactly corresponding to those which are forced into it by the pump. But if the pump propel its fluid, not into a hard unyielding tube of iron or lead, but into an elastic tube of india-rubber, the effect will be very different. The effect of each stroke of the pump will partly be expended in distending the tube, so as to make it contain an additional quantity of water; and the jet at its opposite extremity will be less sudden. In the interval of the stroke, the elasticity of the walls of the tube will cause it to contract again, and to force out the added portion of its contents; this it has not completed by the time that the action of the pump is renewed; and in this manner, instead of an interrupted jet at the mouth of the tube, we have a continuous flow, which, if the tube be long enough, will become quite equable.

275. It is in precisely this manner that the elasticity of the arteries influences the flow of blood through them, by converting the interrupted impulses which the heart communicates to it, into a continued force of movement. In the large arteries, these impulses are very evident; in the smaller branches they are less so, but they still manifest themselves by the *jerking* in the stream of blood proceeding from a wound in one of these vessels; whilst

in the capillaries, the influence of the heart's interrupted impulses cannot usually be seen at all, the streams that pass through them being perfectly equable. The effect thus corresponds exactly with that of the air-vessel of the forcing-pump or fire-engine,* in which the elasticity of compressed air is made to answer the purpose of equalising the stream, which is accomplished in the animal body by the elasticity of the walls of the arteries.

276. The phenomenon which we call the *pulse*, is nothing else than the change in the condition of the artery occasioned by the increased pressure of the fluid upon its walls, at the moment when the heart's contraction forces an additional quantity of blood into the arterial system. By the frequency and force of this change, we can judge of the power with which the blood is being propelled. But the pulse can only be well distinguished, when we can compress the artery against some resisting body, so that there is a partial obstruction to the flow of blood through it, which causes the distention to be more powerful; the most convenient artery for this purpose is the *radial* artery (Fig. 118) at the wrist; but the carotid artery in the neck, and the temporal artery in the temple, may be felt, when it is desired to know the force of the circulation in the head; and the arteries supplying other parts, when we wish to gain information respecting the organs they supply. For an increased action in the organ, whether this be due to inflammation, or to a state of unusual activity of its function, causes an increase of size in the artery which supplies it; and thus the pulsation may be unusually strong in a particular trunk, when the heart's action, and the general circulation, are not in a state of excitement. For instance, a whitlow on the thumb will occasion its artery to beat almost as powerfully as the radial artery usually does; and excessive activity of the mind, prolonged for some hours, greatly increases the force of the pulsations in the carotid arteries, from which the brain is chiefly supplied.

277. The impulse of the heart, and the elasticity of the arteries, which propel the blood through the capillary system, continue to act upon it after it is received into the veins; and

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* See Treatise on HYDRAULICS.

are in fact the chief causes of its movement in them. If we interrupt the current of blood through an artery, by making pressure upon it, and open the corresponding vein, the fluid will continue to flow from the latter, so long as the artery contains blood enough to be forced into the vein by its own contraction; but as soon as it is emptied, the flow from the orifice in the vein will cease, even though the vein itself remains nearly full. If the pressure be then taken off the artery, there is an immediate renewal of the stream from the vein, which may be again checked by pressure on the artery. In the ordinary operation of bleeding, we cause the superficial veins of the arm to be distended, by tying a bandage round them, *above* the point at which we would make the incision; and when an aperture is made, the blood spouts forth freely, being prevented by the bandage from returning to the heart. But if the bandage be too tight, so that the artery also is compressed, the blood will not flow freely from the vein; and the loosening of the bandage will then produce the desired effect. When a sufficient quantity of blood has been withdrawn, the bandage is removed; and the return-flow through the veins being now unobstructed, the stream from the orifice immediately diminishes, so as to be very easily checked by pressure upon it, or may even cease altogether.

278. There is in general very little difficulty in controlling the flow of blood from a wound of a vein lying near the surface; as moderate pressure is sufficient. But the difficulty is much greater when an artery is wounded; for pressure can seldom be effectually applied in the situation of the wound; and the surgeon is generally obliged to tie the vessel above the orifice. As a temporary expedient, the loss of blood may be prevented by making firm pressure upon the artery *above* the wounded part,—that is, nearer the heart; and many valuable lives have been saved, by the exercise of presence of mind, guided by a little knowledge. The best means of keeping up the requisite pressure, until the proper instrument (the tourniquet) can be applied, is to lay over the artery (the place of which may be found by its pulsation) a hard pad, made by tightly rolling or folding

a piece of cloth; this pad and the limb are then to be encircled by a bandage, by which the pressure is maintained; and this bandage may be tightened to any required degree, by twisting it with a ruler or piece of stick. Thus a constant pressure may be exercised upon the artery, which will be generally sufficient to control the bleeding from it. But there are, unfortunately, many cases in which pressure of this kind cannot be applied; as for instance when the femoral artery is wounded high up in the thigh, or the carotid artery in the neck. And nothing else can then be done, but to compress the artery with the thumb, or with some round hard substance (such as the handle of an awl), until proper assistance can be obtained.

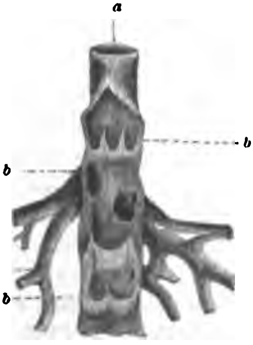

FIG. 122.—VEIN LAID OPEN.

279. We return from this digression (the important practical bearing of which may be its excuse) to the consideration of the forces by which the blood is moved in the veins. These vessels contain a great number of *valves*, which are formed, like the semilunar valves of the aorta (§. 273), by a doubling of their lining membrane. Their situation may be known by the little dilatations which the veins exhibit at the points where they occur; and which are very obvious in the arm of a person not too fat, when it is encircled by a bandage that causes distention of the superficial veins. The structure of these valves is seen at *b b*, Fig. 122; they consist of pocket-like folds of the lining membrane, which allow the blood free passage as it flows towards the heart, but check its reflux into the arteries. Hence it follows that, every time pressure is made upon the veins, it will force towards the heart a portion of the blood they contain, since it cannot be driven in a contrary direction. Now, from the manner in which the veins are distributed, *some* of them must be compressed by almost every muscular movement; these will become refilled as soon as the muscles relax; and they will be again pressed on, when the

movement is repeated. Hence a succession of muscular movements will act the part of a *diffused heart*, over the whole of the venous system, and will very much aid the flow of blood through its tubes. It is partly in this manner that exercise increases the rapidity of the circulation. If the blood is brought to the heart by the great veins more rapidly than usual, the heart must go through *its* operations more rapidly, in order to dispose of the fluid; and if these actions be impeded, great danger of their entire cessation may exist. Hence the importance of bodily tranquillity to those affected with diseases of the heart and lungs. A sudden change of position, from sitting or lying, to standing, has produced immediate death, in numerous instances.

280. Besides the aid thus afforded to the venous circulation, it is probable that there is another cause of the motion of the blood in them, which is independent of the action of the heart and of the arteries. Many facts lead to the belief, that a new force is produced, while the blood is flowing through the capillary vessels;—a force which may, in some instances, maintain the circulation by itself alone. Thus in the capillary system of Plants, no mechanical force can be seen to have any share in the production of the constant and regular flow of fluid through its network. In the lowest Animals also, the heart seems too feeble and imperfect to maintain the circulation, which must partly depend upon some other influence; and even in the highest, there is evidence that the movement of blood in the capillaries may continue for a time, after the action of the heart and of the arteries has ceased to affect it.* This movement seems intimately connected with the changes to which the blood is subservient in the capillaries; for if these be checked, not even the heart's action can propel the blood through them, although no mechanical obstruction exists. Thus, when the admission of air to the lungs is prevented, the blood will not pass through the pulmonary capillaries, since it cannot undergo the change which ought to be performed there; and it therefore accumulates in

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* For a full consideration of this question, see the Author's Principles of General and Comparative Physiology (2nd edition), §§. 369—372; and Principles of Human Physiology, §§. 505—512.

the pulmonary artery, the right side of the heart, and the venous system; and if no relief be afforded, by the admission of air into the lungs, the whole circulation is thus brought to a stand. This condition, which is termed *Asphyxia*, occurs in drowning, hanging, and other forms of suffocation.

Course of the Blood in the different Classes of Animals.

281. The Circulation of the Blood takes place on the same plan, in MAN, in all other MAMMALIA, and in BIRDS. In all the animals included in these groups, the heart is composed of two halves quite distinct from each other, and each possessing an *auricle* or receiving cavity, and a *ventricle* or propelling cavity. The venæ cavæ bring the venous blood from the system into the right auricle, whence it passes into the right ventricle. By the contraction of the latter it is forced into the pulmonary artery, and is carried by it to be exposed to the renewing influence of the air in the lungs. Returning by the pulmonary vein in the state of arterial blood, it is received into the left auricle; and having passed from this into the left ventricle, it is propelled by its contraction into the aorta, which conveys it by its subdivisions into all the capillaries of the system; whence it returns to the heart by the systemic veins, the venæ cavæ. Hence it is evident, that every drop of blood which has passed through the capillaries of the system, must be transmitted to the lungs, before it is allowed again to enter the aorta; and the whole mass of the blood must pass thus through the heart, before any part of it can be transmitted a second time to the vessels from which it was before returned. The two sides of the heart do not possess, when that organ is perfectly formed, any communication with each other, except through the pulmonary vessels; and thus they might be regarded as two distinct organs, united for the sake of convenience. The right side of the heart, being placed at the origin of the pulmonary artery, and having for its office to propel the blood through the lungs, so as to receive the influence of the air, may be called the *respiratory* heart: whilst the left side, which is placed at the origin of the aorta, and has to propel the blood to the body in general, may be called the *systemic*

heart. The circulation would be performed precisely in the same manner, if these two organs were quite distinct from each other; and in fact they are almost so in the *Dugong*, one of the herbivorous Whales (See ZOOLOGY). Moreover in the lower

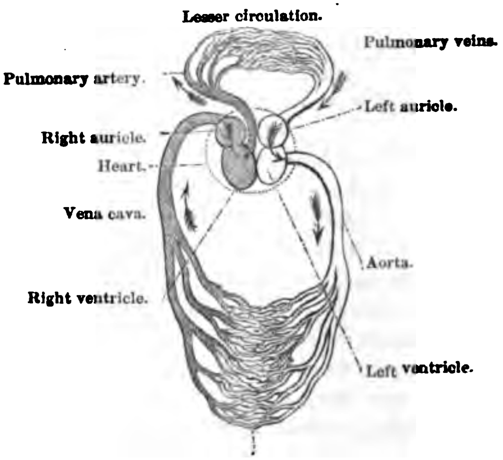


FIG. 123.—CIRCULATION IN MAMMALIA AND BIRDS.

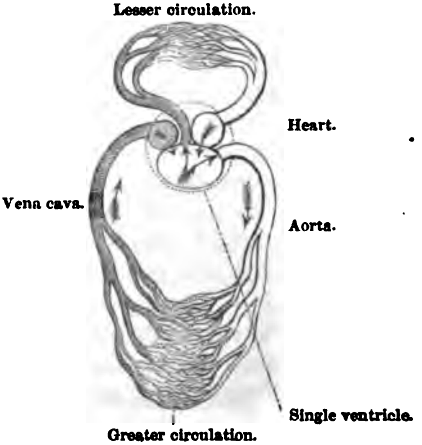


FIG. 124.—CIRCULATION IN REPTILES.

tribes of animals we shall presently find that there is but a *single*, instead of a *double*, heart; and that the organ which is absent is sometimes the systemic, and sometimes the respiratory heart.

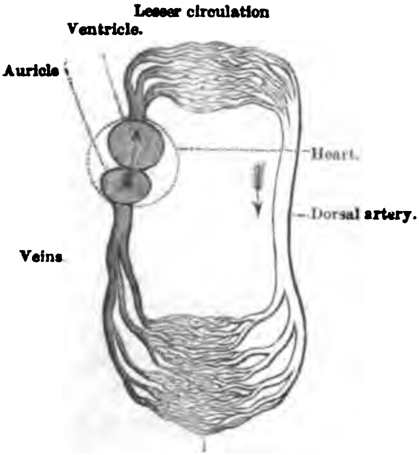


FIG. 125.—CIRCULATION IN FISHES.

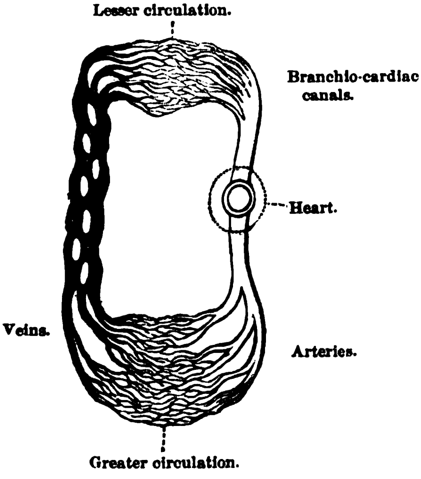


FIG. 126.—CIRCULATION IN CRUSTACEA.

282. The course of the blood in **Mammalia** and **Birds**, which are said to have a *complete double circulation*, is shown by the diagram (Fig. 123). The vessels and cavities of the heart which contain venous blood are shaded; whilst those which convey arterial blood are left white: and this distinction is kept up in the other figures. The direction of the blood is indicated by the arrows.—It must not be supposed, from this account of the progressive course of the blood through the different vessels and cavities, that the action of the left side of the heart takes place at a different time from that of the right, in consequence of its receiving the blood *after* it has passed through the latter; for, as already stated, the two ventricles really contract at the same time. But the left ventricle contracts upon blood, which had been sent by the left into the lungs some seconds before; whilst the right is transmitting a fresh quantity, which it has just received from the system. The amount of blood sent out from either ventricle at each contraction, in a middle-sized man, seldom exceeds 2 ounces; but the whole quantity of blood contained in the body is not less than 28 lbs.: hence, it would require 224 contractions of the heart to propel the whole of this blood through the body, and these (at the ordinary rapidity) would occupy about three minutes. But there is reason to think that the flow of the blood through the body is much more rapid than this; and if such be the case, it is another argument for the existence of an auxiliary power in the capillary vessels (§. 280). It has been calculated, from recent experiments, that the usual force of the heart in man would sustain a column of blood about 7 feet 2 inches high, the weight of which would be about 4 lbs. 3 oz. on every square inch. The backward pressure of this column upon the walls of the heart, or in other words, the force which they have to overcome in propelling the blood into the aorta, is estimated at about 13 lbs.

283. Previously to birth, when the lungs are not yet distended with air, and the aeration of the blood is provided for in other ways, the circulation takes place on a different plan from that on which it is afterwards performed. There exists at that period an opening in the partition between the two auricles, by

which they have a free communication; and there is also a large trunk which passes from the *right* ventricle into the aorta. By these channels, the blood which is received from the systemic veins can pass at once into the aorta, without going through the pulmonary vessels. But when the young animal begins to breathe, these communications are speedily obliterated; the blood is transmitted through the pulmonary vessels to the lungs; and the whole circulation takes place upon the plan just described. There are occasional instances, however, in which the communication between the auricles remains open, so that the double circulation is never perfectly established; for a portion of the blood is allowed to pass from the right to the left side of the heart, without being aerated in the lungs; and the blood which is sent to the system contains, therefore, a mixture of venous with the proper arterial fluid,—a state which will be presently seen to be natural in the Reptile. Such cases are recognised by the blueness of the skin, the lividity of the lips, and the indisposition to bodily or mental exertion. Persons affected with this malformation seldom reach adult age.

284. In the class of REPTILES, there is not a complete double circulation; for a mixture of arterial and venous blood is sent alike to the lungs and to the general system; and no part is supplied with the pure arterialised fluid. In general the heart contains only *three* cavities, two auricles and one ventricle (Fig. 127). One of the auricles receives the venous blood from the

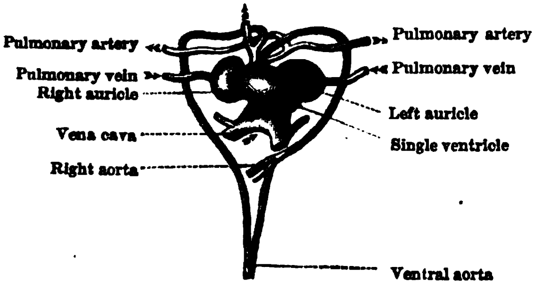
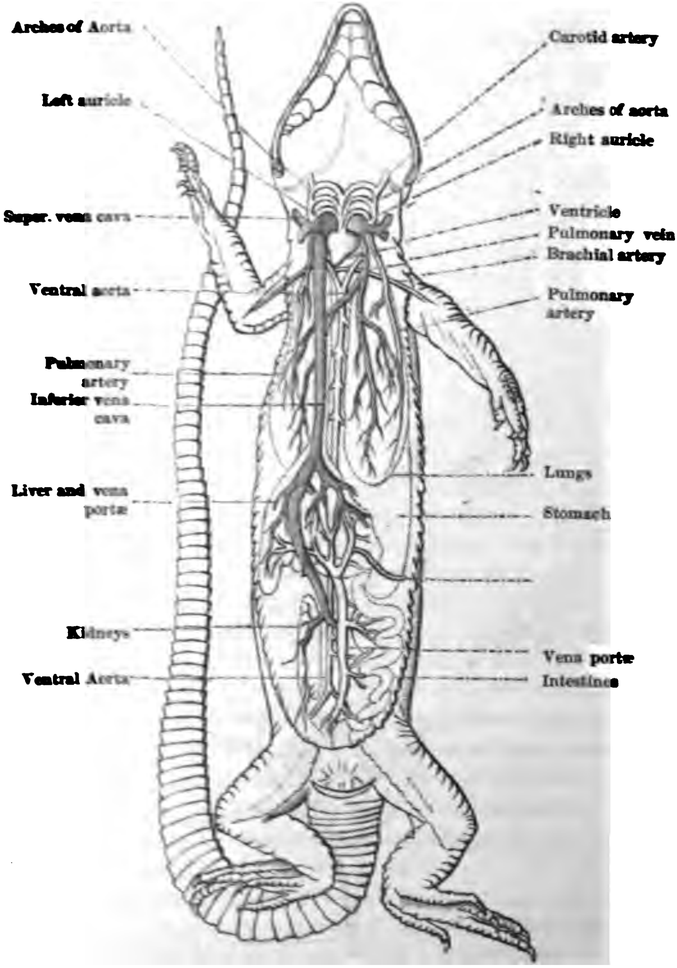


FIG. 127.—HEART OF TORTOISE.

system; whilst the other receives the arterialised blood from the lungs. Both these pour their contents into the same ventricle,



198.—CIRCULATING APPARATUS OF LIZARD.

[illegible] led together; and this mingled blood is transmitted, by the contraction of the ventricle, partly into the lungs, and partly into the aorta (Fig. 124). In some Reptiles there is a partial division of the ventricle, so that the mixture of the arterial and venous blood is not complete; and whilst the blood transmitted to the lungs is *chiefly* that which has returned from the systemic veins, the blood which enters the aorta for the supply of the system is *chiefly* that which has returned from the lungs in an arterialised state. Hence such animals have a circulation which approaches very closely to that of Mammalia and Birds; and it is among them that we find the greatest vigour and activity in this generally inert and sluggish class.

285. The general arrangement of the blood-vessels in Reptiles is shown in Fig. 128. It is seen that the aorta, soon after its origin, divides into three *arches* on either side; and that these, after sending off branches to the head and to the lungs, reunite into a single trunk, which corresponds exactly with the aorta of the higher animals. These arches are in fact the remains of a set of vessels, which will be found to be of the highest importance in Fishes, being there subservient to the aeration of the blood: in the true Reptiles, however, they are never concerned in this function, but they still remain, as if to show the unity of the plan on which this apparatus is formed. Precisely the same arrangement of the vessels may be seen in Birds and Mammalia, at an early period of their development; but it afterwards undergoes considerable changes, by the obliteration of several of the arches; for of the four pairs which may be seen at one period, a single branch only remains on either side; and one of these becomes the permanent arch of the aorta, whilst the other becomes the permanent pulmonary artery.

286. In the class of FISHES, the circulating apparatus is still more simple. The heart only possesses *two* cavities, an auricle and a ventricle. It is placed at the origin of the vessels which are concerned in the aeration of the blood; and it receives and transmits venous blood only; hence it is analogous to the right side, or *respiratory* heart, of Birds and Mammalia. The venous blood, which is brought to it by the systemic veins, is transmitted by its ventricle into a trunk, which subdivides into four

or five pairs of branches or *arches* (Fig. 129). These branches run along the fringes which form the *gills* of the Fish, and send a minute vessel into every one of their filaments (§. 312). Whilst passing through this vessel, the blood is submitted to the influence

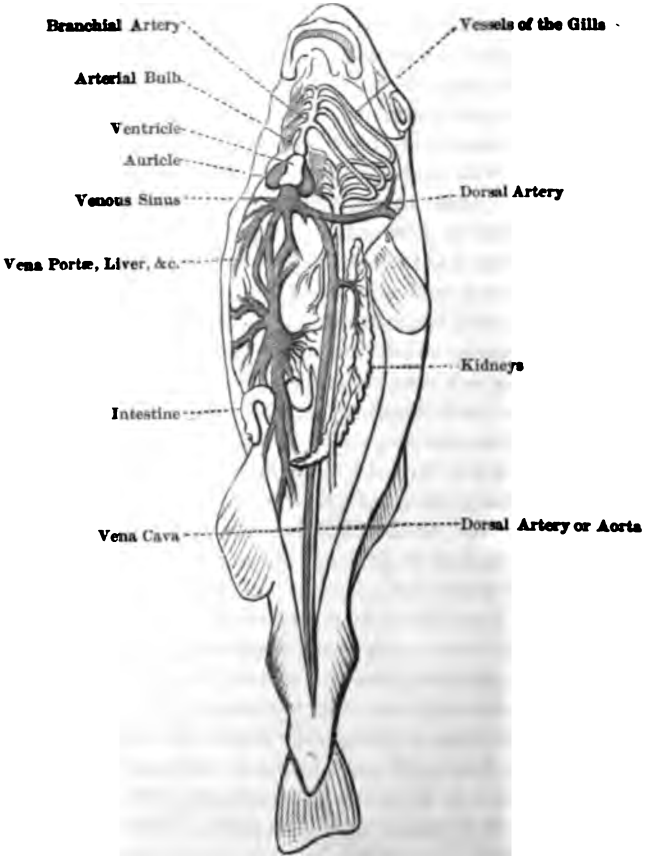


FIG. 129.—CIRCULATING APPARATUS OF FISH.

of the air diffused through the water, to which the gills are freely exposed, and is thus aerated; and it is then collected from the several filaments and fringes, into a single large trunk, analogous to the aorta of the higher animals, by which the whole body is supplied with arterialised blood. After circulating through the system, the blood returns to the heart in a venous condition, and again goes through the same course. This course is represented in a simple form in the diagram, Fig. 125; and it will be seen on a little consideration, that it does not differ from that which exists in Animals with a complete double circulation, in any other essential particular than this—that there is no systemic heart to receive the blood from the gills or aerating organs, and to convey it to the body at large. But, though *all* the blood must necessarily pass through the gills before it can again proceed to the body, it does not follow that the blood should be as completely aerated as in Reptiles, in whose circulation there is a mixture of venous and arterial blood; for the exposure of the blood to the small quantity of air which is diffused through water is not nearly so effectual as its direct exposure to air.

287. There is a group of animals which forms the transition between Fishes and Reptiles; some of them being Fishes at one part of their lives, and Reptiles at another; whilst others remain, during their whole lives, in a condition intermediate between the two groups (§. 95.) Of this group, the common *Frog* is a familiar example. In the Tadpole state, it is essentially a Fish, breathing by means of gills, and having its circulation upon a corresponding plan; but, after it has gone through its metamorphoses, it breathes by lungs, its heart acquires an additional auricle, and the whole plan of the circulation is changed, so as to become conformable to that of the true Reptile. This process takes place, not suddenly, but by progressive stages; and as these are extremely interesting, they will be now briefly described. In Fig. 130 we have a representation of the circulating apparatus of the Tadpole in its fish-like condition. At *a* is seen the large trunk which issues from the ventricle, forming a bulbous enlargement like that which is seen in the corresponding part of the Fish. From this enlargement proceed three trunks on each side, which convey the blood to the gills or *branchiæ*, and are called the branchial arteries (br^1, br^2, br); and after being

aerated by passing through their filaments, it is collected by the branchial veins (*vb*, *vb*). Of these, the first pair transmits its

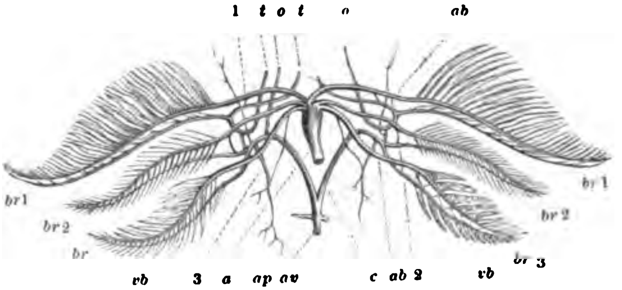


FIG. 180.—BLOOD-VESSELS OF THE TADPOLE, IN FIRST STATE.

blood by the vessels *o*, *o*, *t*, (which are also formed in part by the second pair) to the head and upper extremities; whilst the greater part of the blood of the second pair, with the whole of that of the third, is discharged into the trunk *c* on either side. By the union of that vessel with its fellow, the trunk *a v* is formed; which conveys the blood that has been aerated in the gills, to the general system, and is thus to be evidently regarded as the aorta. But we find here three small vessels (1, 2, and 3), which do not exist in the Fish; and which establish a communication between the bronchial arteries and the bronchial veins, in such a manner, that the blood may pass from the former into the latter, without going through the filaments of the gills. These communicating vessels are very small in the Tadpole, and scarcely any blood passes through them; but it is chiefly by *their* enlargement, that the course of the blood is subsequently altered. There is also a fourth branch, *a p*, which proceeds to the lungs on either side; and as these organs are not yet developed, this pulmonary artery also is at first of very small size.

288. As the metamorphosis of the other parts proceeds, however, and the animal is being prepared for its new mode of life, the lungs are gradually developed, and the pulmonary artery greatly increases in size; whilst the gills, on the other hand, do

not continue to grow with the animal, but rather shrink, from the diminished supply of blood which they receive. For, during this period, the communicating branches increase in size; so that a considerable part of the blood which has been transmitted into the branchial arteries passes at once into the veins, and thence into the aorta, without being made to traverse the gills; its aeration being partly accomplished by the lungs. This state of things is seen in Fig. 131; where *a p*, *a p* are the enlarged pulmonary arteries; and where the communicating branches are seen almost to form the natural continuations of the branchial arteries. A condition of this kind exists permanently in those Animals which retain their gills during their whole lives, and have the lungs imperfectly developed (§. 97).

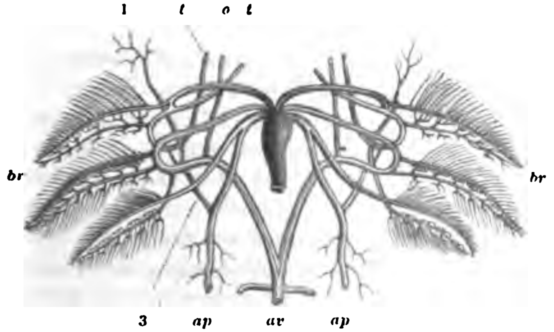


FIG. 131.—THE SAME, IN A MORE ADVANCED STATE.

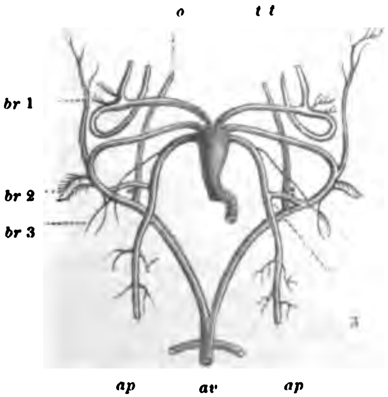


FIG. 132.—THE SAME, IN THE PERFECT ANIMAL.

289. When the metamorphosis is complete, the branchial vessels altogether disappear, but the *arches* still remain, as shown in Fig. 132 The

first of these arches supplies the vessels of the head, *t t*; which also, however, receives a branch *o* from the second arch. The second arch, after giving off that branch, unites with its fellow to form the aortic trunk *a v*. The third arch has completely shrivelled up. And the fourth arch or pulmonary artery has now attained its full size, and is become the sole channel through which the aeration of the blood is effected.

290. In the greater part of the MOLLUSCA, the circulation takes place nearly on the same general plan as in Fishes; the heart having two cavities, and the whole of the blood traversing both the respiratory and the systemic capillaries, between each time of its leaving the heart and returning to it again. But this heart is *systemic*, and not pulmonary; for it receives the arterial blood from the gills, and transmits it to the great systemic artery; and after the blood has been rendered venous by its passage through the capillaries of the body, it enters the vessels which distribute it to the gills, before being again subjected to the action of the heart. The accompanying figure of the circulation in the *Doris* (a kind of sea slug) will serve to show the general distribution of the vessels in this group. The heart consists of a ventricle *a*, whence issues the main artery *b*; and of a single or double auricle *c*, in which terminate the veins, *d*, of the branchial apparatus *e*. The aerated blood which these convey to the heart, is transmitted by it, through the artery *b*, to the system at large; and from this it is collected, in the state of venous blood, by the veins which terminate in the large

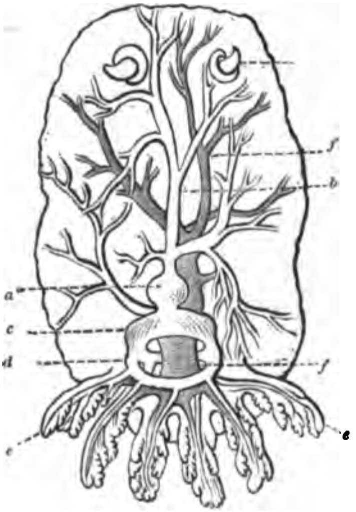


FIG. 133.—CIRCULATING APPARATUS OF DORIS.

trunk *ff.* By this trunk it is distributed to the gills *e;* and thence returns to the heart, after it has undergone aeration. Now if a second heart had been placed on the trunk *ff,* just as it is about to subdivide for the distribution of the blood to the gills, the circulation would have been analogous to that of Birds and Mammalia. There is great variety in the position of the gills in Molluscous animals, and a corresponding variety in the situation of the heart, which is usually placed near them. In the Doris the gills are arranged in a circular form, round the termination of the intestinal canal; but in many Mollusca they form straight rows of fringes on the two sides of the body. In these last, the heart not unfrequently has two auricles; but these are not analogous to the two auricles of Reptiles; for each has the same function with the other—the reception of the blood from the gills of its own side.

291. There is a very interesting variety in the conformation of the heart in the CEPHALOPODA, or *Cuttle-fish* tribe; which seems to form a connecting link between the plan of the circu-

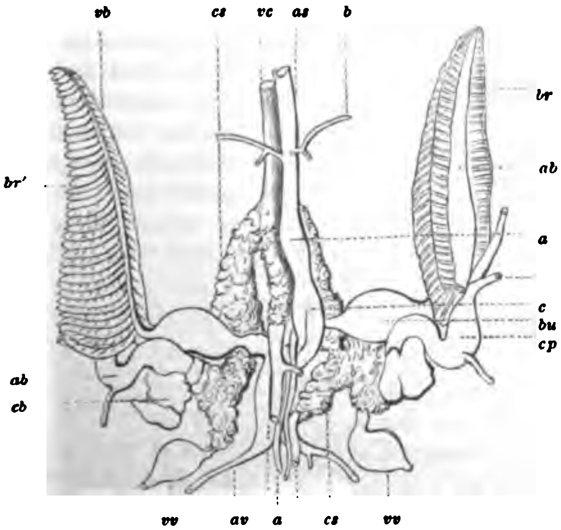


FIG. 134.—CIRCULATING APPARATUS OF CUTTLE-FISH.

lation that prevails among the Mollusca in general, and that which we have seen in the class of FISHES. The auricle and ventricle of the heart are separated from each other; and whilst the latter remains in the position just described, the auricle occupies the place which the whole heart possesses in the class above. The course of the blood in these animals is shown in Fig. 134; where *c* represents the ventricle or systemic heart, from which arises the aorta *a*, *a*, *as*, *av*, that supplies the body with arterial blood. The venous blood is returned through the great vein *v c*, covered with a curious spongy mass *c s*, the use of which is not known; this also receives the blood from the intestinal veins *v v*; and it divides into two trunks which convey the blood to the gills or branchiæ (*br* and *br'*), where it undergoes aeration. On each of these trunks is an enlargement, *c b*, which has the power of contracting and dilating, and thus of assisting the transmission of the blood through the arteries of the gills, *ab*. The blood is returned to the ventricle by the branchial veins, *v b*, on each of which there is another dilatation, *bu*, which might be regarded as analogous to the auricle of the other Mollusca, but is not muscular. Thus in the Cuttle-fish, the blood receives an impulse from the systemic heart, when it is transmitted into the main artery; and when it returns by the systemic veins, it receives another impulse from the branchial hearts, before it passes through the gills;—an arrangement obviously analogous to that which we meet with in the highest Vertebrata.

292. In the *Crab* and *Lobster*, and other animals of the class

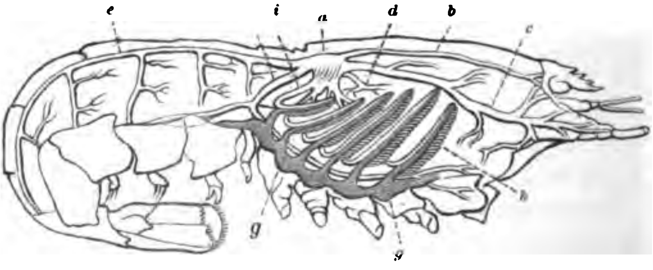


FIG. 135.—CIRCULATING APPARATUS OF LOBSTER.

CRUSTACEA, the blood for the most part follows the same course as in the Mollusca; excepting that the heart contains but a single cavity; and that there are no distinct vessels for veins, these being replaced by irregular channels which are excavated in the tissues, and which present occasional enlargements, termed venous sinuses. The arrangement of the circulating apparatus of a lobster is seen in Fig. 135, in which *a* is the heart; *b* and *c* the arteries to the eyes and antennæ; *d*, the hepatic artery; and *e* and *f*, the arteries which supply the thorax and abdomen. The blood that has been propelled through these by the action of the heart, finds its way into the great venous sinus *gg*, which receives the fluid collected from all parts of the body; from this it passes to the gills, *h*; and thence it is returned to the heart by the branchial veins, *i*. Another view of a portion of the circulating apparatus is given in Fig. 136, which represents a transverse section of it in the region of the heart, with one pair of gills. The heart is seen at *c*; and from its under side proceeds one of the arterial trunks, which conveys the blood to the system. Returning thence, the blood enters the venous sinus *s*, which has an enlargement at the base of each gill; and this seems to act the part of a branchial heart, like the corresponding enlargement on the branchial vessels of the Cuttle-fish. From this cavity, it is carried by the vessel *va* into the branchiæ *b*; and after it has passed through the capillaries of the gill-filaments, it is collected by the vessels *ve*, which carry it to the branchial veins, *vb*, and thence to the heart. The general plan of the circulation in this class is shown in Fig. 126.

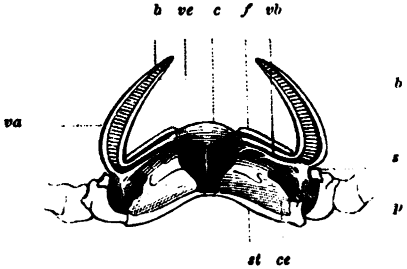


FIG. 136.

293. In the class of INSECTS, we seem to lose all trace of distinct vessels for the conveyance of the blood. Neither arteries nor veins can be detected; but the nutritive fluid is diffused

through the channels or interstices that exist among the different organs. Nevertheless, it has a tolerably regular circulation; and the organ by which this movement is chiefly effected is a long tube, termed the *dorsal vessel*, which seems to propel it forwards, whilst other trunks on the two sides convey it backwards. The dorsal vessel, seen at *a*, is a membranous tube lying along the back of the insect, and partly divided into several compartments by incomplete valvular partitions, which bear no inconsiderable resemblance to the valves of veins. By the successive contraction of these different portions, the blood, which entered at the posterior extremity of the dorsal vessel, is gradually propelled forwards; and when it arrives at the front of the body, it passes out by a series of canals, some of which convey it to the head, whilst others pass sideways and backwards for the supply of the body, with its appendages, the legs and wings. On returning from these parts, it re-enters the posterior end of the dorsal vessel. It is to be remarked that in Insects no special arrangement of vessels for the aeration of the blood is required; since this aeration is accomplished by the conveyance of air, by means of minute air-tubes, into every part of the body, however small (§. 320); a mode of respiration different from any that we notice

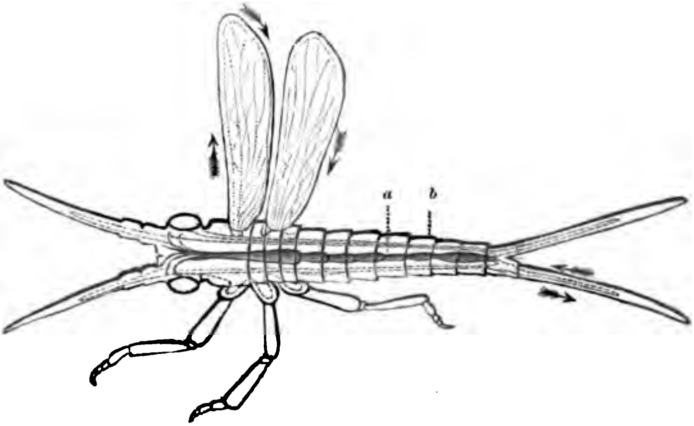


FIG. 137. —CIRCULATION IN INSECTS.

elsewhere. A very similar arrangement is met with in the Spider tribe; but as the body is not so long, the dorsal vessel is less extended in length, and is of larger diameter. This is seen in Fig. 138; where *a* represents the abdomen of the animal; *ar*, the large dorsal vessel or heart; *c*, a trunk passing forwards to the head; and *v*, vessels communicating with the respiratory organs.

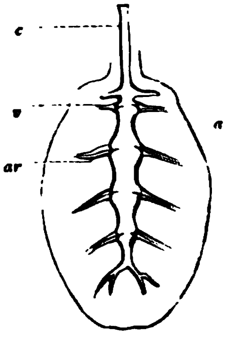


FIG. 138.—DORSAL VESSEL OF SPIDER.

294. In the animals of the *Worm* tribe, belonging to the class Annelida, there is a general similarity in the course of the blood to that which prevails in Insects; but as the respiration is accomplished by means of special organs, which are sometimes diffused along the entire body, and sometimes restricted to one part of it (§. 115), there is considerable variety in the provisions for submitting the blood to the influence of the air; and as these are rather curious than interesting, they will not be here described.* It seems probable that, in some at least of this class, the blood does not always flow through the vessels in the same direction, but that its course is occasionally changed. Such a change occurs in the lowest group of Mollusca, the Tunicata; and also in Zoophytes.

295. In the animals of the class ECHINODERMATA, the *Star-fish*, *Sea-urchin*, &c., there seems to be a regular circulation of nutritious fluid carried on through distinct vessels, but without any definite heart. The only trace, indeed, of anything like a propelling organ is an enlargement of one of the trunks, which *pulsates* with tolerable regularity; but this would not seem to have force enough to propel the fluid through a complex system of vessels; and the circulation seems to be carried on chiefly by some force produced in the capillaries, as in plants (§. 280).

296. This is still more evidently the case in the animals that

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* For a full account of them, see the Author's Principles of General and Comparative Physiology, §. 345—350.

unite into those remarkable compound structures, which we term ZOOPHYTES. Even in the thin walls of the body of the *Hydra*, and of the polypes resembling it in structure, and also in the arms, a movement of fluid takes place, through channels which seem excavated in the soft tissue. But the most curious circulation is that which is seen in the stems and branches of the *Sertularia*, and some other compound polypes (§. 131). When these are examined with a high magnifying power, a current of fluid containing granular particles is seen running along the axis; and this, after continuing one or two minutes in the same direction, changes and sets in the opposite one, in which it continues about as long, and then resumes the first;—thus alternately flowing down the stem to the extremities of the branches, and back again. The rapidity and constancy of these currents seem to depend on the activity of the growth of the parts towards which they are directed.

CHAPTER VI.

OF RESPIRATION.

297. We have seen that arterial blood, by its action on the living tissues, loses those qualities which rendered it fit for the maintenance of life; and that, after having undergone this change, it recovers its original properties by exposure to air. This exposure is necessary, therefore, to the continued existence of Animals in general. If we place an animal under the receiver of an air-pump, and exhaust the air either partially or completely, a great disturbance soon takes place in its various functions; shortly afterwards, the various actions of life cease to take place; and a state of apparent death comes on, which speedily becomes real, if air be not readmitted. The influence of air is not less necessary to Plants than to Animals; for they also die when excluded from it (See VEGET. PHYS., §. 286.): and thus it may be stated to be a general condition, necessary for the continuance of the life of all organised beings.

298. At first sight it might be thought that Animals which always live beneath the surface of the water, such as Fishes, and many Mollusca, are removed from the influence of the air; and that they hence constitute an exception to this general law. But this is not the case; for the liquid which they inhabit has the power of absorbing, and of holding dissolved in it, a certain quantity of air, which they can easily separate, and which is sufficient for the maintenance of their life. They cannot exist in water which has been deprived of air (as by boiling, or by being placed under the exhausted receiver of an air-pump); for they then become insensible and die, just as do Mammalia and Birds, when they are prevented from inhaling air in the ordinary manner.

299. The changes which result from the exposure of the blood or nutritious fluid of Animals to the air, either in the atmosphere, or through the medium of water, form a very important part of their vital actions; and the changes themselves, together with the various mechanical operations by which they are effected, constitute the function of *Respiration*. The nature of these changes will be first explained; and the structure and operations of the organs by which they are performed, will be afterwards described.

Nature of the Changes essentially constituting Respiration

300. Atmospheric air, it has been stated, is necessary to the continued life of all animals; but this fluid is not composed of one element alone. By the science of Chemistry, it is shown to be a mixture of three gases possessing very different properties. Besides the watery vapour with which the atmosphere is always more or less charged, the air contains 21 parts in 100 of *oxygen*, and 79 parts of *nitrogen* or *azote;* with traces of *carbonic acid gas*. The question immediately presents itself, therefore, whether these gases have the same action on animals; or, if their actions are different, to which of them specially belongs the property of thus contributing to the maintenance of life. This question may be decided by a few simple experiments. If we place a living animal in a jar filled with air, and cut off all communication with the atmosphere, it perishes by suffocation in a longer or shorter time; and the air in the vessel, which has thus lost the power of maintaining life, is found, by chemical analysis, to have lost the greater part of its oxygen. If we then place another animal in a jar filled with nitrogen gas, it perishes immediately; whilst if we place a third in pure oxygen, it breathes with greater activity than in air, and shows no sign of suffocation. It is then evident, that it is to the presence of *oxygen* that atmospheric air owes its vivifying properties.

301. But the change produced in the atmosphere by animal respiration is not limited to this. The oxygen which disappears is replaced by a new gas, carbonic acid; which, instead of being favourable, like the preceding, to the maintenance of life, causes

the death of animals which inhale it, even in small quantities. The production of this substance is an action not less general in the Animal kingdom than the absorption of oxygen; and it is in these two changes that the act of respiration essentially consists.

302. The quantity of nitrogen or azote in the air that has been respired varies but very little; and it appears that the principal use of this gas is to *dilute* the oxygen, which, in a state of purity, would act too powerfully on the animal system, and produce in it a state somewhat resembling that of fever. It appears, however, that there is a continual absorption of nitrogen by the blood; and as continual an exhalation of it: and this may be shown to be a necessary result of the laws regulating the diffusion of gases, by which the interchange of elements between the air and the blood is regulated. (See MECHANICAL PHILOSOPHY, §. 41.) When the quantity exhaled, and the amount absorbed, are equal or nearly so (which is usually the case), no change manifests itself in the air which has been breathed; when the quantity absorbed is the greater, there is a diminution in that which the respired air contains; and when the quantity exhaled is the greater, there is a corresponding increase.

303. The differences in the character of the blood which are produced by its exposure to the air have already been noticed (§. 227); and we now see that they are essentially due to the absorption of oxygen, and the setting-free of carbonic acid. The same change will take place out of the living body as well as in it; provided that the blood can be exposed as completely to the influence of the atmosphere. When blood is drawn from a vein into a basin or cup, the dark hue of the surface is usually seen to undergo a rapid change, so as to present the arterial tint; but this change is confined to the upper surface, because it alone is exposed to the influence of the atmosphere. The alteration takes place still more rapidly and completely if the blood be exposed to pure oxygen gas; but even then it is almost confined to the surface. It is not prevented, even though the direct communication between the two be cut off by a membranous partition, as it is in the living animal: for if the blood

be tied up in a bladder, the gas has still the power of penetrating to it, and of effecting the change in it; and the change is manifested, not only by the alteration in the character of the blood, but by the disappearance of a certain quantity of oxygen from the air, and its replacement by carbonic acid. Now if, by spreading out the blood in a very thin layer, we expose a much larger surface to the air, or if, by frequently shaking it, we continually change its surface, we render the change more complete. But still it is accomplished far less effectually than it is in the lungs or gills of a living animal; for when it is passing through their capillaries, it is divided into an immense number of very minute streams, each of which is completely exposed to the influence of the air, and the combined surface of which is very great.

304. The question next arises, what becomes of the oxygen which disappears, and what is the origin of the carbonic acid which is thus produced by respiration? This question will now be considered.

305. When charcoal is burned in a vessel filled with air, the oxygen disappears, and is replaced by an equal bulk of carbonic acid: at the same time there occurs a considerable disengagement of heat. But during respiration, the same phenomena occur; there is always an evident relation between the quantity of oxygen employed by an animal, and the amount of carbonic acid it produces (the latter being usually somewhat less than the former); and, as we shall see hereafter (Chap. IX.), there is always a greater or less amount of heat produced. There exists, then, a great analogy between the principal phenomena of respiration, and those of the combustion of carbon; and this agreement in the results naturally leads to the belief that the causes of both are the same. It was at one time supposed that the oxygen of the inspired air combines, in the lungs themselves, with the carbon brought there in the blood; and thus produces the carbonic acid which is expired, occasioning at the same time the development of heat. But this theory is inconsistent with experiment; for it has been proved that the carbonic acid is not *formed* in the lungs, but that it is brought to them in the

venous blood of the pulmonary artery; and that their office is to disengage or get rid of it, whilst they at the same time introduce oxygen into the arterial blood.

306. This has been proved in various ways. In the first place, it may be shown that a considerable quantity of carbonic acid exists in venous blood, from which it may be removed by drawing it into a vessel filled with hydrogen or nitrogen, or by placing it under the vacuum of an air-pump. It may also be shown that arterial blood contains a considerable quantity of oxygen. Hence the inference seems unavoidable, that the blood, in passing through the lungs, gives off carbonic acid, and takes in oxygen. This view receives full confirmation from the following experiment. If Frogs, Snails, or other cold-blooded animals, be confined for some time in an atmosphere of nitrogen or hydrogen (two gases which do not themselves exert any injurious effect upon them), they will continue for some time to give off nearly as much carbonic acid as they would have done in common air; thus proving that the carbonic acid is *not* formed in the lungs by the union of carbon brought in the venous blood with the oxygen of the air, since here no oxygen was supplied; and showing that the carbonic acid must have been brought ready-formed. But this process could not be continued for any great length of time, even in cold-blooded animals; since a supply of oxygen is necessary to the performance of their various functions. And in warm-blooded animals, a constant supply of this element is so much more important, that they will die if cut off from it, even for a short time.

307. The quantity of oxygen taken in, and of carbonic acid thus disengaged, bears a very regular proportion to the amount of muscular exertion which is made during the same time. Hence it is much greater in tribes whose habits are active than in those who are inert; and it is also greater in the same individual, during a day spent in active exercise, than it is during the same period passed in repose. It is a well-known physiological fact, that, for the continued energy of a muscle, a continued supply of arterial blood is required; and the use of this appears to be twofold. There is much reason to believe that every muscular

contraction, or exercise of *vital force*, is necessarily accompanied by the death of a certain amount of muscular tissue; and for this operation, the presence of the oxygen in arterial blood is required. This oxygen combines with part of the materials thus set free as *waste* (§. 160), and converts them into the products that are thrown off by the various excretions. One of the chief of these products is carbonic acid, which is carried off by the lungs in the manner already described. Thus, the presence of oxygen in the blood is essential to muscular force; and the elements of the blood itself are required to re-form the tissue which has been thus destroyed.

308. Hence we see why the quantity of carbonic acid thrown off by respiration should be increased by muscular exertion. It is among Birds and Insects that we find the greatest quantity produced, in proportion to the size of the animals; and in both these classes, we find extraordinary provisions for the energetic performance of this function (§§. 320 and 326). The greater energy of the respiration of Birds than that of Mammalia, when compared with the greater number of the red corpuscles in their blood, gives an increased probability to the idea, that the red corpuscles are the *chief* carriers of oxygen from the lungs to the capillaries of the system, and of carbonic acid from the capillaries of the system to those of the lungs (§. 234). The energetic respiration of Insects, though these corpuscles are absent, is fully accounted for by the peculiar manner in which the air enters every part of their bodies. In no case do we see the influence of muscular activity on the amount of carbonic acid thrown off more strongly manifested than in Insects. A *humble-bee*, while in a state of great excitement after its capture, made from 110 to 120 respiratory movements in a minute; after the lapse of an hour, they had sunk to 58; and they subsequently fell to 46. In the first hour of its confinement, it produced about 1-3rd of an inch of carbonic acid (a quantity many times greater, in proportion to its size, than that which Man would have set free in the same time); and during the whole twenty-four hours of the subsequent day, the insect produced a less amount than that which it then evolved in a single hour.

In the larva state, which is usually one of comparative inactivity, the respiration is not above that of the neighbouring tribes, such as the Myriapoda; and in the Chrysalis state of those which become completely inactive, the amount of respiration is still lower.

309. This Chrysalis state bears a strong resemblance to the torpid condition, in which many animals pass the winter. Reptiles and most Invertebrata that inhabit the land, become (to all appearance) completely inanimate, when the temperature is lowered below a certain point; yet retain the power of exhibiting all their usual actions, when the temperature rises again. In this state, their circulation and respiration appear to cease entirely; or, if the functions are performed at all, they take place with extreme feebleness; and the animals may be prevented from reviving for a long time, without their vitality being permanently destroyed, if they be surrounded by an atmosphere sufficiently cold. Thus Serpents and Frogs have been kept for three years in an ice-house, and have completely revived at the end of that period. Snails may be reduced to a similar state by the want of water; and may be kept in it for almost any length of time. Among Mammalia there are several species which pass the winter in a state of torpidity; but this is less profound than the torpidity of cold-blooded animals, for the circulation and respiration never entirely cease, though they become very slow. There are various gradations between this condition, and ordinary deep sleep. Thus some of the animals which *hybernate* or retire to winter quarters, lay up a supply of food in the autumn, and pass the cold season in a state differing but little from ordinary sleep, from which they occasionally awake, and satisfy their hunger. But others, like the Marmot, are inactive during the whole period, taking no food, and exhibiting scarcely any evidence of life, unless they are aroused. It appears from Dr. M. Hall's experiments and observations, that the Bat, when in a state of complete torpidity, consumes no oxygen, and forms no carbonic acid, though its circulation continues languidly. But a very slight irritation is sufficient to produce respiratory movements.

310. Animals will in general bear deprivation of air well or

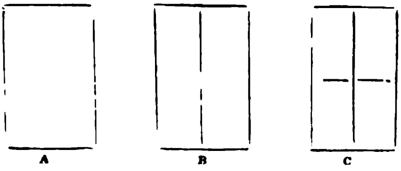
badly, according as the respiration is more or less active. Thus a warm-blooded animal usually dies, if sunk beneath water for more than a few minutes; though there are some which are enabled, by peculiar means, to sustain life much longer (§. 265). In cold-blooded animals, however, whose demand for oxygen is much less energetic, this treatment may continue for a much longer time without the loss of life. Thus the common Water-Newts naturally pass a quarter of an hour or more beneath the surface, without coming up to breathe; and they may be kept down for many times that period, without serious injury to them. And, as we might expect from their peculiar condition, warm-blooded, hybernating animals may be kept beneath water for an hour or more, without apparent suffering; although the same animals, in their active condition, would not survive above three minutes. There is reason to believe that a similar condition may be produced in Man, by the influence of mental emotion, or of a blow on the head, at the moment of falling into the water; so that recovery is by no means hopeless, even though the individual may have been more than half an hour beneath the surface.

Structure and Actions of the Respiratory Apparatus.

311. In animals whose organisation is most simple, the act of respiration is not performed by any organ expressly set apart for it; but it is effected by all the parts of the body, that are in contact with the element in which the animal lives, and from which they derive their necessary supply of oxygen. This is the case, for example, in the lower class of Animalcules, in the Polypes, Jelly-fish, Entozoa, and many other animals. Even in the higher classes, a considerable amount of respiratory action takes place through the skin, especially when it is soft and but little covered with hair, scales, &c., as in Man, and in the Frog tribe; but we almost invariably find in them a prolongation of this membrane, *specially* designed to enable the blood and the air to act upon each other, and having its structure modified for the advantageous performance of this function. This modification consists in the peculiar *vascularity* of this membrane, that is,

in the large number of vessels that traverse its surface; and also in the thinness of the membrane itself, by which gases are enabled to permeate it the more readily. Moreover, we always find this membrane so arranged, that it exposes a very large surface to the air or water which comes into contact with it; and we shall find that this surface may be immensely extended, without any increase in the size of the organ. Thus the small lungs of a Rabbit really expose a much larger respiratory surface to the air, than is afforded by the large air-sacs of a Turtle, which are ten times their size. This is effected by the minuteness of the subdivision of the former into small cavities or air-cells, whilst the latter remain as almost undivided bags.

312. It is desirable to possess a distinct idea of the mode in which the surface is thus extended by subdivision. We may, for the purpose of explanation, compare the lung to a chamber, on the walls of which the blood is distributed, and to the interior of which the air is admitted. This chamber, for the sake of convenience of description, we shall suppose to have two long and two short sides, as at A. Now if a partition be built up in the direction of its length, as at B, a new surface will be added equal to that which the two *sides* previously exposed; since *both* the surfaces of this partition are supplied with blood, and are exposed to the air. Again, if another partition be built up across the chamber, as at C, a new surface will be added, equal to that which the *ends* of the chamber previously exposed. And thus, by the subdivision of the first chamber into four smaller ones, the extent of surface has been doubled. Now if each of these small ones were divided in the same manner, the surface would again be doubled; and thus, by a continual process of subdivision, the surface may be increased to almost any extent compatible with the free access of air to the cavities, and of blood to the walls. In the same manner, where the respiratory membrane is prolonged outwardly, so as



to form *gills*, which hang from the exterior of the body (as is the case in most aquatic animals), its surface is very much extended by disposing it in folds, and by dividing these folds into fringes, so as to expose a large surface to the water. It has been calculated that, by this kind of arrangement, the gills of the Skate present a surface four times as great as that of the human body.

313. The structure and arrangement of the respiratory organs differ according as they are destined to come in contact with air in the state of gas, or to act upon water in which a certain amount of it is dissolved. In the former case, we usually find the respiratory membrane (which is but a prolongation of the skin or general envelope) forming the wall of an *internal* cavity,—just in the same manner as the membrane, through which the act of absorption takes place in animals, is prolonged from the skin, so as to form the wall of the digestive cavity (§. 14). Such a cavity for the reception of air into the interior of the body, exists in all air-breathing animals; and in the Vertebrata it receives the name of *lung*. On the other hand, in animals that breathe by means of water, the respiratory surface is prolonged *externally*, so as to be evidently but an extension of the general surface,—just in the same manner as the roots of plants are prolonged into the soil around them. These prolongations, termed *gills*, which may have various forms, carry the blood to meet the surrounding water, and to be acted on by the air it contains; and then return it to the body in a purified condition.

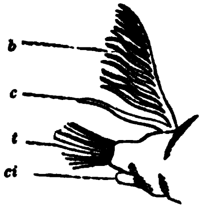


FIG. 139.—GILL-TUFT OF EUNICE.

314. The form and arrangement of the gills vary greatly in the different classes of aquatic animals. Sometimes they simply consist of little leaf-like appendages, which have a texture rather more delicate than that of the rest of the skin, and which receive a larger quantity of blood. In other instances, they are composed of a number of branching tufts, which are more copiously supplied with vessels. In the class ANNELIDA, we

observe a great variety in the mode in which these tufts are disposed; and this is connected with the general habits of the animal. Thus in the *Serpula* (Fig. 58), whose body is enclosed in a tube, the tufts are disposed around the head alone, and spread out widely into the semblance of a flower. In the *Nereis* (Fig. 57) and its allies, they are set upon nearly every division of the body, and are much smaller. Their usual arrangement in these marine worms may be seen in Fig. 139, which represents one of the appendages of *Eunice*. The tuft of gills is shown at *b*; at *c* is seen a bristle-shaped filament, which may perhaps be regarded as the rudiment of a leg; and the letters *t* and *ci* point to other projections, which also seem connected with the movements of the animal. In the *Arenicola* (the lob-worm of fishermen) we find the respiratory tufts disposed on certain segments only, and possessing more of an arborescent (tree-like) form (Fig. 140).

FIG. 140.—ARENICOLA.

315. A somewhat similar arrangement is seen in the larvæ of many aquatic INSECTS, which breathe by means of gills; although all perfect Insects breathe air in the manner to be presently described. In Fig. 141 is represented the larva of the *Ephemera* (May-fly), which breathes by means of a series of gill-tufts disposed along the abdomen, and also prolonged as a tail. In the CRUSTACEA, we usually find the gills presenting the form of flattened leaves or plates. In the lower tribes of the class, they project from the surface of the body; but in the higher, they are enclosed within a cavity, through which a stream of water is made constantly to flow, by mechanism adapted for the purpose. Their form and position in the Crab are shown at *b*, *b′*, Fig. 48. Although

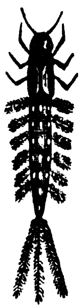


FIG. 141.—LARVA OF EPHEMERA.

these animals usually reside in the water, or only quit it occasionally, there are some species, known under the name of *land-crabs*, which have the power of living for some time at a distance from water. In order to prevent their gills from drying up, which would destroy their power of acting on the air, there is a kind of spongy structure in the gill-chamber, by which a fluid is secreted, that keeps them constantly moist.

316. In the Mollusca we find the gills arranged in a great variety of modes. In the lowest class, the TUNICATA, the respiratory membrane is merely the lining of the large chamber formed by the mantle, through which a stream of water is continually made to flow (§. 319); and this surface is sometimes extended, by the folding or plaiting of the membrane. In most of the CONCHIFERA, however, we find four *lamellæ* or folds of membrane (*br*, Fig. 142), lying near the edge of the shell, and copiously supplied with blood-vessels. In the *Oyster*, these are freely exposed to the surrounding element, the lobes of the mantle being separated along their entire length; but where

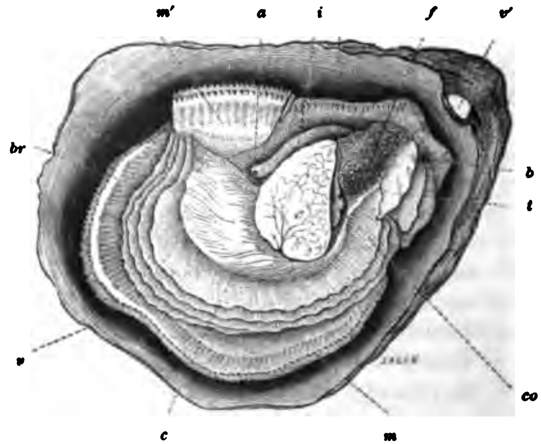


FIG. 142.—ANATOMY OF THE OYSTER.

v, one of the valves of the shell; *v'*, its hinge; *m*, one of the lobes of the mantle; *m'*, a portion of the other lobe folded back; *c*, muscles of the shell; *br*, gills; *b*, mouth; *t*, tentacula, or prolonged lips; *f*, liver; *i*, intestine; *a*, anus; *co*, heart.

these are united, so as to shut in the gills, there are two orifices, often prolonged into tubes (as in the *Tellina*, Fig. 143), through one of which the water is drawn in for the purpose of respiration, whilst through the other it passes out, as in the Tunicata. In the aquatic GASTEROPODA there is scarcely any part of the body to which we do not find the gills attached in some species or other. In the naked marine species, which may be called Sea-slugs, they form fringes, which are sometimes disposed along the sides of the body, as in the *Glaucus* and *Tritonia*, sometimes arranged in a circle around the end of the intestine, as in the *Doris* (see also Fig. 133); and are sometimes covered in, more or less completely, by a fold of the mantle. In most of the species that possess shells, the gills form comb-like fringes, which are lodged in a cavity enclosed in the last turn of the spiral shell; and to this cavity the water is admitted, sometimes by a large opening, sometimes by a prolonged tube. In the CEPHALOPODA, we find the gills composed of a collection of little leaf-like folds, placed on a stalk (*br*, *br*, Fig. 134); they are enclosed in a cavity which is covered in by the mantle; and the walls of this cavity have the power of alternately dilating

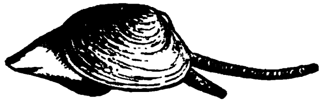


FIG. 143.—TELLINA.

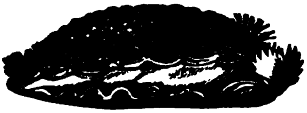


FIG. 144.—TRITONIA.

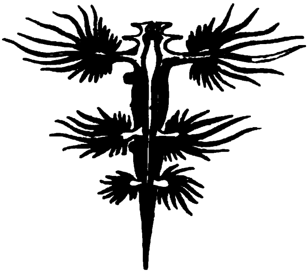


FIG. 145.—GLAUCUS.

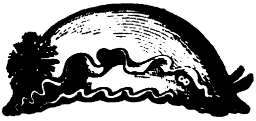


FIG. 146.—DORIS.

and contracting, so as to draw in and expel water. It communicates with the exterior by two orifices, one of which, *o* (Fig. 147), a wide slit, is for the entrance of water; whilst the other, *t*, is tube-like, and serves not only to carry off the water that has passed over the gills, but also to convey away the excrements, and the fluid ejected by the ink-bag. This is called the funnel.

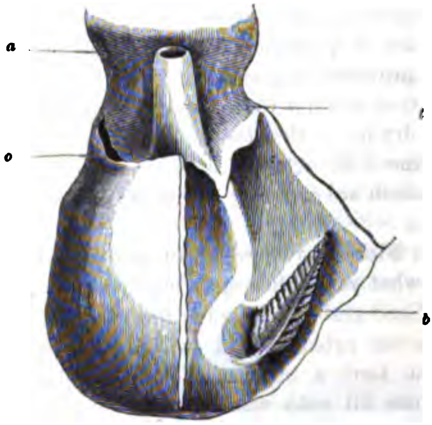


FIG. 147.—GILLS OF POULP.

317. In FISHES, the gills are composed of fringes, which are disposed in rows on each side of the throat, and are covered by the skin. The cavity in which they lie has two sets of apertures; one communicating with the throat, and the other opening on the outside. In the Fishes with a cartilaginous skeleton, we usually find as many of these external orifices as there are rows of gills; thus in the *Lamprey* there are seven, as shown in the subjoined figure (*a*). But in Fishes with a bony skeleton, there is usually but a single large orifice on either side; and this is covered with a large valve-like flap, which is termed the *operculum* or gill-cover. A continual stream of water is made to pass over the gills by the action of the mouth, which takes in a large quantity of fluid, and then forces it through the apertures on each side of the throat, into the gill-cavities; and from these it passes out by the other

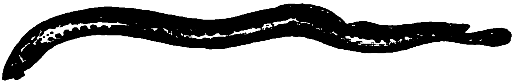


FIG. 148.—LAMPREY.

orifices just described. Fishes, in common with other animals that breathe by gills, can only respire properly, when these are kept moist, and are so spread out as to expose their surface to the surrounding element. The act of respiration can take place when they are exposed to *air*, provided these conditions are fulfilled; but in general it happens that, when a Fish is taken out of water, its gills clog together and dry up, so that the air cannot exert any action upon them; and the Fish actually dies of suffocation, under the circumstances which are necessary to the life of an air-breathing animal.

318. There are certain Fishes, however, which are provided with an apparatus, somewhat resembling that which has been already described in the Land-crab, for keeping the gills moist. The bones of the pharynx are extended and twisted in such a remarkable manner, as to form a number of small cavities. These cavities, the Fish can fill with water; and they form a reservoir of fluid, from which the gills may be supplied with a sufficient amount, to keep them moist during some time. The gill-filaments themselves are so arranged that they do not clog together; and by this combination of contrivances, the species of Fish that are furnished with it can live for a long time out of water, so as to be able to journey for a considerable distance on land. Such a provision is

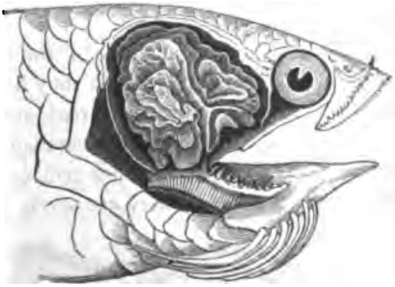


FIG. 149.—RESPIRATORY APPARATUS OF ANABAS.

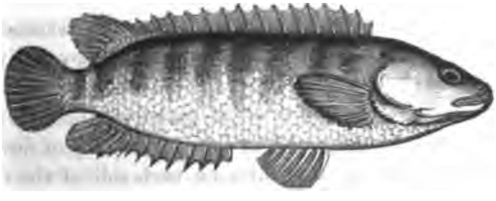


FIG. 150.—ANABAS.

especially desirable in tropical climates, where shallow lakes are often dried up by a continued drought, so that their inhabitants must perish, if they were not thus enabled to migrate. One of the most curious of these Fishes (most of which are inhabitants of India and China) is the *Anabas* or climbing-perch of Tranquebar; which climbs bushes and trees in search of its prey, a species of land-crab, by means of the spines on its back and gill-covers. The gills of the Amphibious Reptiles, in their Tadpole state, resemble those of Fishes, and are connected with the mouth in the same manner.

319. In the respiratory actions of nearly all these animals a very important part is performed by the *cilia* (§. 117) which cover the surfaces of the gills. Even in those which do not possess any special respiratory organs (§. 311), the action of the cilia is very important, in causing a constant change in the water that is in contact with their surface. Thus in the Polypes, which are for the most part fixed to one spot, the action of the cilia produces currents in the surrounding water. On the other hand, in the actively-moving Animalcules, the same action propels their bodies rapidly through the water; though in some of them, which occasionally fix themselves like Polypes, the action of the cilia resembles theirs. In either case, there is a continual change in the layer of water which is in immediate contact with the surface; and thus a constant supply of the air contained in the water is secured. A similar action goes on, still more energetically, on the gill-tufts of the Annelida; and this action continues after the death of the animal, or after the tuft has been separated from it, producing evident currents in the water in which it is placed. It is by the action of the cilia alone, that the continual current of water is kept up through the respiratory chamber of the lower Mollusca; and even where this current is maintained in other ways, as in the Cephalopods and Fishes, we still find the gills covered with cilia, by the action of which an interchange in the water, that is in contact with each individual filament, is secured. This action may be well observed in the Tadpole of the common Water-Newt, whose gills hang from the neck on either side; the cilia are themselves so minute that they

cannot be distinguished; but the motion of the water may be readily perceived in a tolerable microscope, especially when small light particles, such as powdered charcoal, are diffused through it.

320. In animals whose blood is made to act directly upon the air, we usually find a provision of some kind for introducing the air into the interior of the body. The simplest arrangement is that which we meet with in the Snail and Slug; and it consists merely of a cavity, resembling that in which the gills are

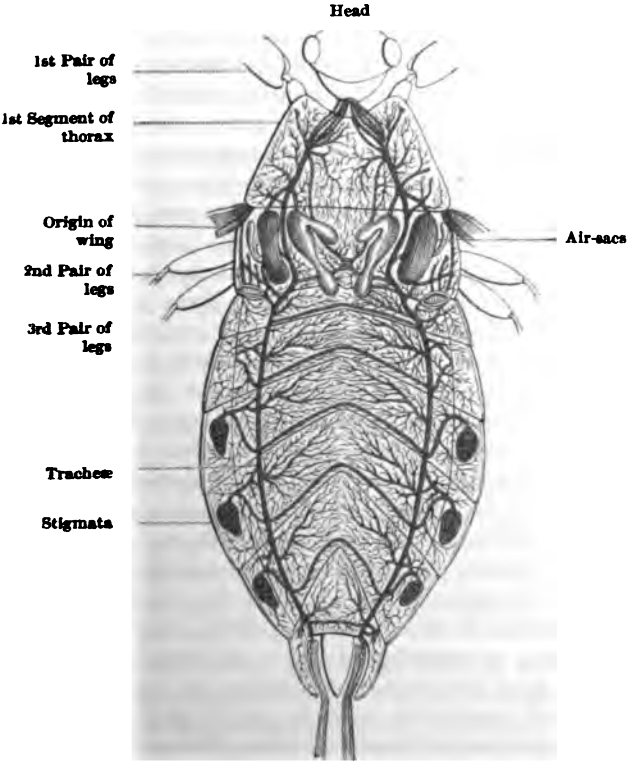


FIG. 151.—RESPIRATORY APPARATUS OF INSECT (NEPA).

disposed in the aquatic Mollusca, but having a free communication with the external air, and having the blood minutely distributed by vessels upon its walls (*p*, Fig. 14). In the air-breathing Annelida, such as the *Earth-worm*, we find a repetition of similar cavities along the body, one pair usually existing in each segment; and these open externally by small apertures, which are termed *stigmata*. The same is the case in the MYRIAPODA; but the air-sacs now begin to send off branching air-tubes or *tracheæ*, which spread through the body; these, however, have not much communication with each other. In INSECTS, this plan of structure is carried out in the most remarkable manner. The stigmata do not open into distinct air-sacs, but into canals, which lead to two large tracheæ that run along the sides of the body, and are connected by several tubes that pass across it—one usually for each segment. From these tracheæ others branch off, which again subdivide into more minute tubes; and by the ramifications of these, even the minutest parts of the body are penetrated (Fig. 151). These tubes are formed upon a similar plan with the air-vessels of Plants, having a spiral fibre winding inside their outer membranous coat; by the elasticity of which fibre, the tube is kept from being closed by pressure.

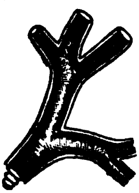


FIG. 152.—AIR-TUBE OF INSECT.

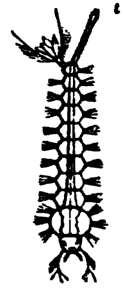


FIG. 153.—LARVA OF GNAT.

321. In this manner the air is brought into contact with almost every portion of the tissue, and is enabled to act most energetically upon it; and thus the feeble circulation of these animals (§. 293) is in a great degree counterbalanced by the extraordinary activity of their respiration. There are no animals which consume so much oxygen, in proportion to their size, as Insects do when they are in motion; but when they are at rest, their respiration falls to the low standard, of the tribes to which they bear the greatest general resemblance. In the larva state, the respiration is sometimes accomplished by means of gills, and sometimes by tracheæ, according to the habits and residence of the animal;

but it is never very active. Some aquatic larvæ breathe air by means of tracheæ; and they are consequently obliged, like the Whales and other aquatic Mammalia, to come occasionally to the surface, for the purpose of gaining a fresh supply of air. The larva of the Gnat, which breathes in this manner, has one of the stigmata of its tail-segment prolonged into a tube; and it may often be seen suspended, as it were, in the water, with its head downwards, the end of this tube (*t*, Fig. 153) being at the surface.

322. In most perfect Insects, we find the tracheæ dilated at certain parts into large air-sacs (Fig. 151); these are usually largest in Insects that sustain the longest and most powerful flight; in some of which, as in the common Bee, they occupy a much larger portion of the trunk, than they do in the insect whose system of air-tubes has been just represented,—this insect, the *Nepa* or Water-Scorpion being of aquatic habits, and seldom using its wings for flight. There can be little doubt that one use of these cavities, is to diminish the specific gravity of the Insect, and thus to render it more buoyant in the atmosphere; but it would not seem improbable, that they are intended to contain a store of air for its use while on the wing, as at that time a part of the spiracles are closed. We shall find in Birds, the Insects of the Vertebrated division, a structure bearing remarkable analogy to this (§. 326.)

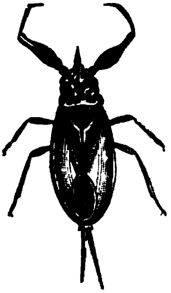


FIG. 154.—NEPA.

323. In some of the ARACHNIDA, such as the *Cheese-mite*, the respiration is accomplished by tracheæ, as in Insects; but in the *Spiders* it is performed by a different kind of apparatus. Instead of opening into a system of prolonged tubes, each spiracle leads to a little chamber, the lining membrane of which is arranged in a number of folds, that lie together like the leaves of a book; and thus a large surface is exposed to the air, which is admitted through the spiracles. This arrangement is shown in Fig. 46.

324. Hitherto it has been seen that the respiratory apparatus

is not connected with the mouth; which, in the Invertebrated classes, has the reception of food as its sole function. On this account, we cannot regard the air-sacs of Insects as bearing any real analogy to the lungs of Vertebrata, which are formed by an extension of the mucous membrane of the digestive cavity. The simplest condition of the true lung is that which constitutes the air-bladder of Fishes. This we sometimes find in the condition of a closed bag, lying along the spine; and its use cannot be that of assisting respiration, since air is not admitted to it from without. But in other cases, we find it connected with the intestinal tube by means of a short wide duct; and, as many Fishes are known to *swallow* air, which is highly charged with carbonic acid when it is again expelled, it seems probable that their air-bladder effects this change in precisely the same manner as a lung would do—the air being transmitted to it from the intestine. There are some Fishes in which the resemblance of the air-bladder to a lung is more decided, and its connexion with the function of Respiration is evidently more important. The canal by which it communicates with the alimentary canal opens into the latter above the stomach, and, even in some instances, at the back of the mouth; so that a gradual approach is seen to the arrangement which exists in air-breathing animals. In these Fishes, as in the Amphibia that retain their gills (§. 97), it would appear that the respiration is accomplished partly by the lungs, and partly by the gills; this is the case in the curious *Lepidosiren* (Fig. 37), which, as formerly mentioned, is regarded by some naturalists as a Fish, and by others as a Reptile.

325. The lungs of REPTILES are for the most part but little divided; so that, although they hold a very large quantity of air, this does not act advantageously upon the blood, in consequence of the small surface over which the two are brought together (§. 312). In *Serpents* we find but a single lung, that of one side not being developed; and this lung extends along nearly half the length of the body. Reptiles have no power of filling their lungs by a process resembling our *inspiration*, or drawing-in of air; but they are obliged to swallow it, as it were, by the action of the mouth. The skin of Frogs is of great im-

portance in their respiration—in fact, of almost as much consequence as their lungs. The necessity for more energetic respiration increases in these animals with the temperature, every rise in which excites them to greater activity. During the winter, which they pass beneath the water in a state of torpidity, the action of the water upon their skin is sufficient to aerate their blood. When spring returns, and brings with it a warmer temperature, which arouses them from their inaction, they need a larger amount of respiration, and come occasionally to the surface, to take in air by their lungs. And when summer comes on, the greater heat increases their need of respiration; and they quit the ponds, in order to allow the atmosphere to act upon their skin, as well as upon their lungs. If they are prevented from doing so, they will die; and the same result follows if the skin be smeared with grease, so that the air cannot permeate it. Moreover, if the lungs be removed, and the animal be made to breathe by its skin alone, it may live for some time, if the temperature be not high. These facts show the great importance of the skin as a respiratory organ in Frogs.

326. The respiration of Birds is more active than that of any other Vertebrata; that is, they consume more oxygen, and

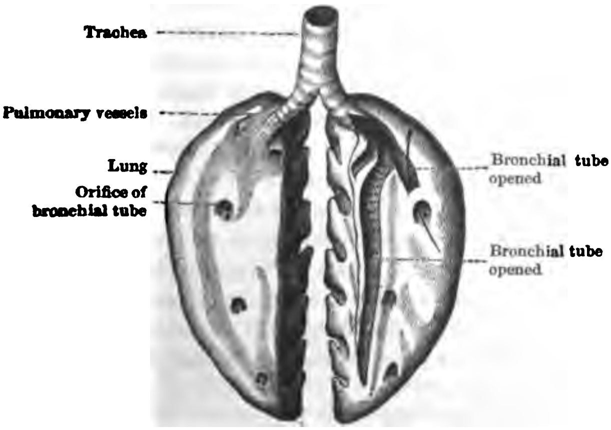


Fig. 155.—Air-tubes and Lungs of Birds.

form more carbonic acid, in proportion to their size. Their lungs, however, are not so minutely subdivided as are those of Mammalia; but the surface over which the air can act upon the blood is immensely extended, by a provision which is peculiar to this class. The air introduced by the windpipe, passes not only into the lungs properly so called, but into a series of large air-cells, which are disposed in various parts of the body, and which even send prolongations into the bones, especially in Birds of rapid and powerful flight, whose whole skeleton is thus traversed by air. The mode in which some of the *bronchial tubes*, or subdivisions of the windpipe, pass from the lungs to these air-cells, is shown in Fig. 155. Now, by this arrangement, a much larger quantity of air is taken in at once, and a much more extensive surface is exposed to its action, than could otherwise be provided for; and as the air which is received into the air-cells has to pass through the lungs, not only when it is taken in, but when it is expelled again, its full influence upon the blood is secured.

327. Birds, like Reptiles, are destitute of the peculiar apparatus by which Mammalia are enabled to fill their lungs with air; but it is introduced without any effort on their parts. For the cavity of the trunk is almost surrounded, as we have seen (§. 88), by the ribs and breast-bone; and the elasticity of the former keeps it generally in a state, corresponding to that of our own lungs, when we have taken in a full breath. Thus the state of *fullness* is natural to the lungs and air-cells of Birds. When the animal wishes to renew their contents, however, it compresses the walls of the trunk, so as to diminish its cavity, and to force out some of the air contained in the lungs, &c.; and when the pressure is removed, the cavity returns to its previous size by the elasticity of its walls, and a fresh supply of air is drawn into the lungs. The air-sacs answer the same purpose in Birds as in Insects, diminishing the specific gravity of the body, by increasing its size without adding to its weight, and thus rendering it more buoyant.

328. In *Man* and the other MAMMALIA, the lungs are confined to the upper portion of the cavity of the trunk, termed the *thorax;* which is separated from the abdomen by the *diaphragm*,

a muscular partition of which the use in respiration is very important. An imperfect diaphragm is found in some Birds, which approach most nearly to the Mammalia in their general structure. The lungs are suspended, as it were, in this cavity, by their summit or apex; and are covered by a serous membrane termed the *pleura*, which also lines the thorax, being *reflected* from one surface to the other precisely in the manner of the pericardium. Thus the pleura of the outer surface of the lung is continually in contact with that which forms the inner wall of the thorax; they are both kept moist by fluid secreted from them; and they are therefore so smooth, as to glide over one another with the least possible friction. The lungs themselves are very minutely subdivided; and thus expose a vast extent of surface in proportion to their size. The air-cells of the human lung, into which the air is conveyed by the branches of the wind-pipe, and on the walls of which the blood is distributed, do not average above the 1-100th of an inch in diameter. In the accompanying figure is represented, on one side, the lung, *d*, presenting its natural appearance; and on the other, the ramifications of the air-passages or *bronchial* tubes, *c*, *e*, by which air is conveyed into every part of the lungs. The *trachea* or windpipe, *b*, opens into the pharynx or back of the mouth by the larynx, *a*. The construction of this is especially destined to produce the *voice;* and will be explained under that head (Chap. XIII.); but it may be here mentioned that the entrance from the pharynx into the larynx consists of a narrow slit, which is capable of being enlarged or closed by the contraction of muscles. These muscles are made to act by a process corresponding with that which is

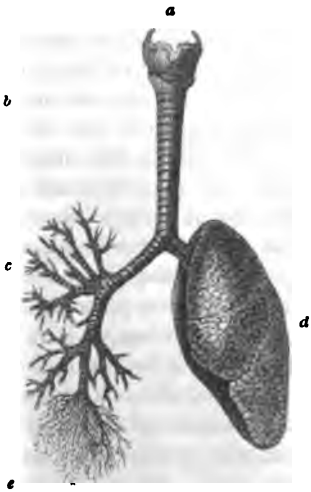


FIG. 156.—AIR-TUBES AND LUNG OF MAN.

concerned in deglutition (§. 195); and the purpose of this is, to prevent the entrance of anything injurious into the windpipe. Thus if we attempt to breathe carbonic acid gas, which would produce an immediately fatal result if introduced into the lungs, the glottis, which forms the walls of this chink, immediately closes, and so prevents its entrance. The contact of liquids or of solid substances, too, usually causes the closure of the glottis, so that they are prevented from finding their way into the windpipe; but this does not always happen, especially when the glottis is widely opened, to allow the breath to be drawn in (§. 193).

329. The larynx, trachea, bronchial tubes, and air-cells of the lungs, in all air-breathing Vertebrata, are lined by a mucous membrane, which is continued from the back of the mouth; and this membrane, like the gills of aquatic animals, is covered with cilia, which are in continual vibration. It is obvious, however, that the purpose of this ciliary movement must be here different from that which is fulfilled by the same action on the surface of the gills (§. 193); and it probably serves to get rid of the secretion, which is being continually poured out from the surface of the mucous membrane, and which, if allowed to accumulate there, would clog up the air-cells, and in time produce suffocation. The vibration of the cilia is observed to be always in one direction,—towards the outlet; and it is in this direction, therefore, that the fluid is gradually but regularly conveyed. The ciliary movement may be seen to take place on the surface of the mucous membrane of the nose; but not on that of the pharynx, where it would be continually interrupted by the passage of food.

330. The constant renewal of the air in the lungs is provided for, in the Mammalia, by a peculiar mechanism, which accomplishes this purpose most effectually, though itself of the most simple character. We must recollect that the *thorax* in this class is an entirely *closed* cavity. It is bounded above and at the sides by the ribs (the space between which is filled up by muscles, &c.), and below by the diaphragm, which here forms a complete partition between the thorax and abdomen. The

whole of this cavity, with the exception of the space occupied by the heart and its large vessels (and also by the gullet, which runs down in front of the spine) is constantly filled up by the lungs. Now the size of this cavity may be made to vary considerably;—in the first place, by the movement of the diaphragm,—and in the second, by that of the ribs.

331. I. The diaphragm, in a state of rest or relaxation, forms a high arch, which rises into the interior of the chest, as at *g*, Fig. 157; but when it contracts, it becomes much flatter (though always retaining some degree of convexity upwards), and thus adds considerably to the capacity of the lower part of the chest. The under side of the diaphragm is in contact with the liver and stomach, which, to a certain degree, rise and fall with it. It is obvious that, when the diaphragm descends, these organs, with the abdominal viscera in general, must be pushed downwards; and as there can be no yielding in that direction, the abdomen is made to bulge forwards, when the breath is drawn in. On the other hand, when the contraction of the diaphragm ceases, the abdominal muscles press back the contents of the abdomen, force up the liver and stomach against the under side of the diaphragm, and cause it to rise to its former height.

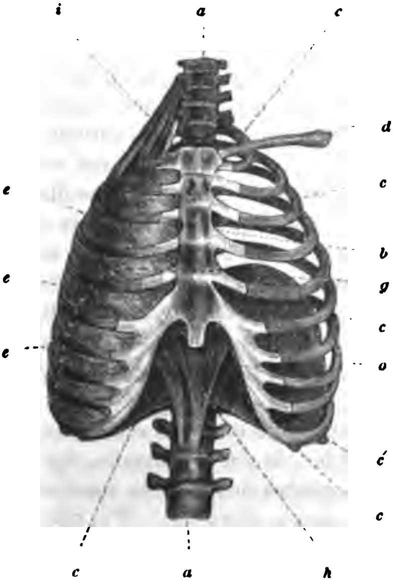


FIG. 157.—THORAX OF MAN.

332. II. The play of the ribs is rather more complicated. These bones, *c c*, and *c′ c′* (to the number of twelve on each side in Man) are attached at one end by

a movable joint to the spinal column, *a*; whilst at the other they are connected with the sternum (breast-bone) by an elastic cartilage. Now each rib, in the empty state of the chest, curves downwards in a considerable degree; and it may be elevated by a set of muscles, of which the highest, *i*, are attached to the vertebræ of the neck and to the first rib, whilst others *e*, *e*, *e*, (termed intercostals) pass between the ribs. The cartilages also curve downwards in the opposite direction, from their points of attachment to the sternum. When the breath is drawn in, the first rib is raised by the contraction of the muscles, *i*; and all the other ribs, which hang (as it were) from it, would of course be raised by this action to the same degree. But each of them is raised a little more than the one above it, by the contraction of its own intercostal muscle; and thus the lower ribs are raised very much more than the upper ones. Now by the raising of the ribs, they are brought more nearly into a horizontal line; as are also their cartilages; and as the combined length of the two is greater the nearer they approach to a straight line, it follows that the raising of the ribs must throw them further out at the sides, and increase the projection of the sternum in front,—thus considerably enlarging the capacity of the chest in these directions. When the movement of inspiration is finished, the ribs fall again, partly by their own weight, partly by the elasticity of their cartilages, and partly by the contraction of the abdominal muscles which are attached to their lower border.—For the full understanding of this description, it is desirable that the reader should examine the movements of his own or another person's chest; by placing his fingers upon different points of the ribs, and watching their changes of position during the drawing-in and the expulsion of the breath.

333. Now the cavity of the thorax is itself perfectly closed; so that, if it were not for the expansion of the lungs, a void or vacuum would be left, when the diaphragm is drawn down, and the ribs are elevated. The air around presses to fill that vacuum (see Treatise on Pneumatics); but this it can only do by entering the lungs through the windpipe, and inflating them (or blowing them out), so as to increase their size in proportion to the increase of the space they have to fill. In this manner the lungs are

made constantly to fill the cavity of the chest, however great may be the increase in the latter. But if we were to make an aperture through the walls of the chest, the air would rush directly into its cavity, when the movements of inspiration are performed, and the lung of that side* would not be dilated. The same thing would happen, if there were an aperture in the lung itself, allowing free communication between one of the larger bronchial tubes and the cavity of the chest; for the air, although still drawn in by the windpipe, would pass directly into the cavity of the chest, rather than dilate the lung, which thus becomes entirely useless. Such an aperture is sometimes formed as the result of disease; and if the action of both lungs were thus prevented, death must immediately take place from suffocation.

334. The extent of the respiratory movements varies considerably; but in general it is only such, as to change about the seventh part of the air contained in the lungs. It may be generally noticed, that every fifth or sixth inspiration in Man is longer and fuller than the rest. Their number varies according to age, and to the state of the nervous system; being faster in infants and in young persons, than in adults; and more rapid in states of mental excitement, or irritation of the bodily system, than in a tranquil condition. In general, from 14 to 18 inspirations take place every minute in an adult; but the number becomes greater, if the attention of the person, whose respirations are being counted, is directed to it. The average quantity of air taken in at each inspiration seems to be about 20 cubic inches; so that, reckoning 16 inspirations to take place per minute, nearly 20,000 cubic inches pass through the lungs in an hour, and 460,224 cubic inches, or 266⅓ cubic feet, in the twenty-four hours. The air which has passed through the lungs contains about 1-26th part of carbonic acid; and thus about 17,856 cubic inches (or rather more than 10 cubic feet) of that gas, containing 2616 grains or about 5½ ounces of solid carbon, are thrown off in the course of twenty-four hours.

335. Now carbonic acid, when diffused through the atmosphere to any considerable amount, is extremely injurious to

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* Each lung has its own cavity; the two being completely separated from each other by the pericardium (§ 255).

animal life; for it prevents the due excretion by the lungs, of that which has been formed within the body; and the latter consequently accumulates in the blood, and exercises a very depressing influence on the action of the various organs of the body, but particularly on that of the nervous system. The usual proportion is not above 1 part in 1000; and when this is increased to 1 part in 100, its injurious effects begin to be felt by Man, in headache, languor, and general oppression. Now it is evident, from the statements in the last paragraph, that, as a man produces in twenty-four hours about 10 cubic feet of carbonic acid, if he were enclosed in a space containing 1000 cubic feet of air (such as would exist in a room 10 feet square and 10 feet high), he would in twenty-four hours communicate to its atmosphere from his lungs, as much as 1 part in 100 of carbonic acid, provided that no interchange takes place between the air within and the air outside the chamber. The amount would be further increased by the carbonic acid thrown off by the skin, the quantity of which has not yet been determined.

336. In practice, such an occurrence is seldom likely to take place; since in no chamber that is ever constructed, except for the sake of experiment, are the fittings so close, as to prevent a certain interchange of the contained air with that on the outside. But the same injurious effect is often produced by the collection of a large number of persons for a shorter time, in a room insufficiently provided with the means of ventilation. It is evident that if 12 persons were to occupy such a chamber for two hours, they would produce the same effect with that occasioned by one person in twenty-four hours. Now we will suppose 1200 persons to remain in a church or assembly-room for two hours; they will jointly produce 1000 cubic feet of carbonic acid in that time. Let the dimensions of such a building be taken at 80 feet long, 50 broad, and 25 high; then its cubical content will be (80 × 50 × 25) 100,000 cubic feet. And thus an amount of carbonic acid, equal to 1-100th part of the whole, will be communicated to the air of such a building, in the short space of two hours, by the presence of 1200 people, if no provision is made for ventilating it. And the quantity will be greatly increased, and the injurious effects will be proportionably greater, if there

is an additional consumption of oxygen, produced by the burning of gas-lights, lamps, or candles.

337. Hence we see the great importance of providing for free ventilation, wherever large assemblages of persons are collected together, even in buildings that seem quite adequate in point of size to receive them; and much of the weariness which is experienced after attendance on crowded assemblies of any kind, may be traced to this cause. In schools, factories, and other places where a large number of persons remain during a considerable proportion of the twenty-four hours, it is impossible to give too much attention to the subject of ventilation; and as, the smaller the room, the larger will be the *proportion* of carbonic acid its atmosphere will contain, after a certain number of persons have been breathing in it for a given time, it is necessary to take the greatest precaution, when several persons are collected in those narrow dwellings, in which unfortunately the poorer classes are compelled to reside. Even the want of food, of clothing, and of fuel, are less fertile sources of disease, than insufficient ventilation; which particularly favours the spread of contagious diseases, by keeping in the poison, and thus concentrating it upon those who expose themselves to its influence.

338. When the quantity of carbonic acid in the air accumulates beyond a certain point, it speedily produces suffocation and death. This is occasioned by the obstruction to the flow of blood through the capillaries of the lungs, which takes place, when it is no longer able to get rid of the carbonic acid with which it is charged, and to absorb oxygen in its stead. The general principle to which this stagnation may be referred, has already been noticed (§. 280). Now, as *all* the blood of the system, in warm-blooded animals, is sent through the lungs, before it is again transmitted to the body, it follows that any such obstruction in the lungs must bring the whole circulation to a stand. The functions of the nervous system are directly dependent upon a *constant* supply of arterial blood (Chap. x.); and accordingly, as the blood which is sent to it under such circumstances becomes more and more venous in its quality, and is at the same time diminished in quantity, its actions first become

irregular, producing violent convulsive movements, and at last cease altogether, the animal becoming completely insensible. In this condition, the pulmonary arteries, the right side of the heart, and the large veins which empty themselves into it, are gorged with dark blood; whilst the pulmonary veins, the left side of the heart, and the arteries of the system, are comparatively empty. Hence the action of the right side of the heart comes to an end, through a loss of power in its walls, occasioned by their being over-distended; whilst that of the left side ceases, for want of the stimulus of the contact of blood, by which the muscular fibre is excited. If this state be allowed to continue, death is the consequence; but if the carbonic acid in the lungs be replaced by pure air, the flow of blood through their capillaries recommences,—the right side of the heart is unloaded, and begins to act again,—arterial blood is sent to the left side, and excites it to renewed motion,—and the same being propelled by it to all parts of the body, their several functions are restored, the nervous system recovers its power of acting, and all goes on as before.

339. Now all these changes occur in exactly the same manner, when a warm-blooded animal is made to breathe nitrogen or hydrogen; since these gases do not perform that which it is the office of oxygen to effect,—the removal of carbon from the system, in the form of carbonic acid. And they also take place in a perfectly pure atmosphere, when the individual is prevented from receiving it into its lungs, by an obstruction to its passage through the windpipe, such as that produced by hanging, strangulation, drowning, &c. For the air in the lungs, not being renewed, speedily becomes charged with carbonic acid, to an extent that checks the circulation through their capillaries; and all the consequences of this follow as before. The most efficient remedy in all such cases, is evidently that suggested by the facts stated in the last paragraph,—the renewal of the air in the lungs. This may be accomplished in various ways, such as blowing into them with the mouth or with a pair of bellows; but the most effectual mode, where it can be employed, is the application of galvanism, by which the diaphragm is made to

contract, and thus to perform a natural inspiratory movement, which is much more efficient, as well as less injurious, than the forcible inflation of the lungs.

340. The ordinary movements of respiration belong, like those of swallowing, to the class of *reflex actions* (§. 195). We have seen that, in every such movement, a great number of muscles are called into play simultaneously; and this is effected by means of the stimulus which is sent to them from the spinal cord. But this stimulus does not originate there; for it is the consequence of impressions conveyed to the spinal cord, and especially to its upper end, by several nerves,—some originating in the lungs, and others in the general surface. The nerves originating in the lungs convey to the spinal cord the impression produced by the presence of venous blood in their capillaries: of this impression, we are not ordinarily conscious; but if we hold our breath for a few moments, we become aware of it; and it speedily becomes so distressing, as to *force* us to breathe, even though we may try to resist it by an effort of the will. The impression conveyed by the nerves of the general surface, is chiefly that produced by the application of cold to the skin. It is this which is the cause of the first inspiration in the new-born infant; which is not unfrequently prevented, by the seclusion of its face (the part most capable of receiving this impres-pression) from the influence of the air. Every one knows that, when the face is dipped into water, an inspiratory movement is strongly excited; and the same happens when a glass of water is dashed over the face. This simple remedy will often put a stop to hysterical laughter, by producing a long sighing inspiration. A still stronger tendency to draw in the breath is experienced, in the first dash of water over the body in the shower-bath. The respiratory movements, in the higher Animals, are placed under the control of the will, to a certain extent, because on them depend the production of sounds, and in Man the actions of speech; but that they are quite independent of the will, and even of sensation, is shown by the fact, that they will continue after the *brain* has been completely removed, provided the spinal cord and its nerves are left without injury. In most of the

Invertebrata, they are connected with distinct ganglia, which minister to them alone. (See Chap. x.)

341. The actions of *sighing*, *yawning*, *sobbing*, *laughing*, *coughing*, and *sneezing*, are nothing else than simple modifications of the ordinary movements of respiration, excited either by mental emotions, or by some stimulus originating in the respiratory organs themselves. *Sighing* is nothing more than a very long-drawn inspiration, in which a larger quantity of air than usual is made to enter the lungs. This is continually taking place in a moderate degree, as already noticed (§. 334); and we notice it particularly, when the attention is released after having been fixed upon an object, which has excited it strongly, and which has prevented our feeling the insufficiency of the ordinary respiratory movements. Hence this action is only occasionally connected with mental emotion. *Yawning* is a still deeper inspiration, which is accompanied by a kind of spasmodic contraction of the muscles of the jaw, and also by a very great elevation of the ribs, in which the shoulders and arms partake. The purely involuntary character of this movement is sometimes seen in a remarkable manner in cases of palsy; in which the patient cannot raise his shoulder by an effort of the will, but does so in the act of yawning. Nevertheless the action may be performed by the will, though not completely; and it is one that is particularly excited by an involuntary tendency to imitation, as every one must have experienced, who has ever been in company with a set of yawners. *Sobbing* is the consequence of a series of short convulsive contractions of the diaphragm; and it is usually accompanied by a closure of the glottis; so that no air really enters. In *hiccup*, the same convulsive inspiratory movement occurs; and the glottis closes suddenly in the midst of it; and the sound is occasioned by the impulse of the column of air in motion, against the glottis. In *Laughing*, a precisely reverse action takes place; the muscles of expiration are in convulsive movement, more or less violent, and send out the breath in a series of jerks, the glottis being open. This sometimes goes on until the diaphragm is more arched, and the chest more completely emptied of air, than it could be by an ordinary movement of expiration. The act of *Crying*, though occasioned by a

contrary emotion is, so far as the respiration is concerned, very nearly the same. We all know the effect of mixed emotions, in producing something "between a laugh and a cry."

342. The purposes of the acts of *coughing* and *sneezing* are, in both instances, to expel substances from the air-passages, which are sources of irritation there; and this is accomplished in both, by a violent expiratory effort, which sends forth a blast of air from the lungs. *Coughing* occurs, when the source of irritation is situated at the back of the mouth, in the trachea, or bronchial tubes. The irritation may be produced by acrid vapours, or by liquids or solids, that have found their way into these passages; or by secretions which have been poured into them in unusual quantity, as the result of disease; and the latter will be the more likely to produce the effect, from the irritable state in which the lining membrane of the air-passages already is. The impression made upon this membrane is conveyed by the nerves spread out beneath its surface, to the spinal cord; and the motor impulses are sent to the different muscles, which combine them in the act of coughing. This act consists, 1st, in a long inspiration, which fills the lungs; 2nd, in the closure of the glottis at the moment when expiration commences; and, 3rd, in the bursting open (as it were) of the glottis, by the violence of the expiratory movement, so that a sudden blast of air is forced up the air-passages, carrying before it anything that may offer an obstruction. The difference between coughing and *Sneezing* consists in this,—that in the latter, the communication between the larynx and the mouth is partly or entirely closed, by the drawing together of the sides of the veil of the palate over the back of the tongue; so that the blast of air is directed more or less completely through the nose, and in such a way as to carry off any source of irritation that may be present there.

343. Besides serving for the *aeration* of the blood, the respiratory organs of Animals, like those of Plants, have the power of throwing off, or *exhaling*, a considerable amount of watery vapour; and also (under certain conditions) of *absorbing* it. Every one is aware that the air he breathes forth contains a large quantity of vapour; this is not perceptible in a warm atmo-

sphere, because the watery particles remain dissolved in it, and do not affect its transparency; but in a cold atmosphere, they are no longer held in suspension, and consequently present the appearance of fog or steam. The quantity of fluid which thus passes off is by no means trifling,—probably not less than from 16 to 20 ounces in the twenty-four hours. A portion of it undoubtedly proceeds from the moist lining of the mouth, throat, &c.; but the greater part is thrown off by the lungs themselves. Various substances of an odoriferous character, which have been taken into the blood, manifest their presence in this exhalation; thus turpentine, camphor, and alcohol, communicate their odour to the breath; and when the digestive system is out of order, the breath frequently acquires a disagreeable taint, from the reception of putrescent matters into the blood.

344. It has been ascertained by experiment, that, when a very warm atmosphere loaded with dampness is breathed, there is rather an absorption than an exhalation of aqueous vapour; and the same may probably take place in a less degree, in an ordinary atmosphere, when the body has been drained of its fluid. In this manner, perhaps, we are partly to account for the extraordinary increase in weight which the body undergoes, by absorption from the atmosphere, under peculiar circumstances (§. 220). That absorption may take place through the lungs, is evident, also, from the effects upon the system of certain gases, which act as violent poisons, even when respired in very small proportion. Thus a Bird is speedily killed by breathing air, which contains no more than 1-1500th part of sulphuretted hydrogen; and a Dog will not live long in an atmosphere containing 1-800th part of this gas. The effects of carburetted hydrogen are similar; but a larger proportion is required to destroy life. Both these gases are given off by decomposing animal and vegetable matter; the neighbourhood of which is consequently very injurious to health.

CHAPTER VII.

OF SECRETION.

General Purposes of the Secreting Process.

345. We have seen that the blood, in the course of its circulation, not only deposits the materials that are converted into the several fabrics of which the body is composed, but also takes up into itself the products of the decomposition, which is continually going on in its various parts; and it is to replace this, that the constant Nutrition of the tissues is required. In order that the blood may retain its fitness for the purposes to which it is destined, it is requisite that these products should be drawn off from the current of the circulation, as constantly as they are received into it; and this is accomplished by the various processes of Secretion, which are continually taking place in different parts of the body. The uninterrupted performance of these is even more essential to the maintenance of life than the uninterrupted supply of nutritive materials; for an animal may continue to exist for some time without the latter, but it speedily dies if either of the more important secretions be checked. We have a striking instance of this in the case of the Respiration, which may be regarded as a true function of Secretion, having for its object to set free Carbonic acid from the blood in a gaseous form, —thereby contributing to the introduction of Oxygen into the blood, for the various important actions to which that element is subservient, especially the maintenance of Animal Heat. (Chap. IX.) The effects of a suspension of the respiratory process, even for a few minutes, in a warm-blooded animal, have been shown (§. 338) to be certainly and speedily fatal; and they are as certainly fatal in the end in cold-blooded animals, though a longer time is required to produce them.

346. A distinction may be not improperly made between the true *secretions*, which are substances elaborated or separated from the blood, not so much to purify it, as to answer some purpose in the animal economy; and the *excretions*, whose sole or principal object is to carry off substances that cannot be retained in the blood, consistently with the maintenance of its purity. The former vary considerably in the different classes of Animals; the latter are the same, as to their essential characters at least, through the whole Animal kingdom, and for this it is not difficult to find a reason. It will be remembered that the ultimate elements of the Animal tissues are four in number: oxygen, hydrogen, carbon, and nitrogen; and that the materials which make up the chief part of the fabric of different classes of animals —albumen, fibrin, gelatin, and fatty matter—contain these elements united in constant proportions, from whatever source we obtain them. Hence we should expect to find the products of their decomposition also the same; and this is, for the most part, the case. Of these four ingredients, oxygen can never be said (in the healthy state at least) to be superfluous in the body; for a large and constant supply of it is required, to unite with the others and carry them off in their altered conditions. Thus, unless oxygen were continually introduced into the system, for the sake of uniting with the carbon that is to be thrown off by Respiration, that excretion must be checked; and it is required, in like manner, for uniting with hydrogen to form water, and with compounds of nitrogen to form urea. Hence there is no need of an organ to carry off the superfluous oxygen; but an organ to introduce it is rather required; and this purpose, as we have seen, is answered by the Respiratory apparatus. But we find organs of excretion specially destined to carry off the carbon, hydrogen, and nitrogen, which are set free, under various forms, by the decomposition of the tissues. Thus the Respiratory organs, as we have seen, throw off *carbon* in the form of *carbonic acid*, and *hydrogen* which has been in like manner united with oxygen so as to form *water*. On the other hand, the Liver has for its office to separate the same elements from the blood in a different form, throwing them off in the condition of a peculiar *fatty*

matter, which consists almost entirely of carbon and hydrogen. The function of the liver is the most active, when that of the respiratory organs is least so, and *vice versâ.* Of this we shall presently meet with some remarkable examples (§. 365). Lastly, the Kidneys have for their chief object to throw off the *azotised* compounds which result from the decomposition of the tissues; these contain a very large proportion of azote or nitrogen, which is united with the other elements into the crystalline compounds, *urea*, and *uric* or *lithic* acid, the latter of which is usually thrown off in combination with ammonia.

347. It is obvious that, when an animal has retained its usual weight for any length of time without change, the total weight of its excretions must be equivalent to the total weight of the solids and fluids taken in. If these last have been no more in amount than was absolutely necessary for the maintenance of the body during that period, all the azotised portions of the food was first appropriated to the formation of the azotised tissues; whilst the non-azotised portion was used up in maintaining the respiration (§. 157). Consequently, no part of the food would pass *at once* into the biliary and urinary excretions; and these would have no other function, than to separate, or strain off, as it were, the products of the decomposition of the tissues formed from it, when their term of life had expired (§. 161). But it is certain that Man (as well as other animals which have in some degree learned his habits) frequently consumes much more food than is necessary for the supply of his wants, and a little consideration will show, that the surplus must pass off by these excretions, without ever forming part of the living fabric; for new muscular tissue is not formed in proportion to the quantity of aliment supplied, but in proportion to the demand created by the exercise of it (§. 589); consequently, if more food is taken in, than is necessary to supply that demand, no use can be made of it. We never find that a Man becomes more *fleshy* by eating a great deal and taking little exercise; indeed the very contrary result happens. But let him put his muscles to regular and vigorous exercise, and eat as much as his appetite demands, and they will then increase both in strength and bulk.

348. Hence, if *more azotised* food be taken in, than is required to supply the waste of the muscular and other azotised tissues, the surplus must be carried off by the organs of excretion—chiefly, indeed almost entirely, by the Kidneys. By throwing upon them more than their proper duty, they become disordered, and unable to perform their functions; hence the materials which they ought to separate from the blood, accumulate in it, and give rise to various diseases of a more or less serious character, which might have been almost certainly prevented by due regulation of the diet. The most common of these diseases among the higher classes are Gout and Gravel; both of these may be traced to the same cause,—the accumulation in the blood of lithic acid, which results from the decomposition of the superfluous azotised food, and which the kidneys are not able to throw off in the proper state,—that is, dissolved in water. That these diseases are, comparatively speaking, rare among the lower classes, is at once accounted for by the fact, that they do not take in any superfluous azotised food;—all that they consume being appropriated to the maintenance of their tissues, and the kidneys having only to discharge their proper function of removing from the blood the products of the decomposition of these. Hence the *radical cure* of these diseases, in most persons who have a sufficiently vigorous constitution and firm resolution to adopt it, is abstinence from all azotised nutriment—whether contained in animal flesh, bread, or other articles of vegetable diet,—but such as is required to supply the wants of the system.

349. The case of the late Dr. James Gregory, a celebrated Professor and Physician of Edinburgh, is an apposite illustration of the importance of this precept. He was descended from a decidedly gouty family; and between the ages of 23 and 30, he himself suffered from several attacks. By using active exercise, however, avoiding all excesses, and using moderation in diet (although he did not abstain from animal food) during a period of twenty years, he so completely overcame the disposition to the disease, that all symptoms of it disappeared in the latter part of his life. If such abstinence be carried too far,

however, it will produce injurious instead of beneficial results, weakening the system, and impairing the digestive powers; and if food be employed of a kind which is liable to produce *lactic* acid (the acid that appears in milk, when it turns sour), much disorder may still remain, which must be avoided by using the kind of diet that is least liable to undergo this change.

350. Again, if *more non-azotised* food is taken into the system than can be got rid of by Respiration, it must either be deposited as fat, or it must be separated from the blood, and carried off by the excretion of the Liver. If too much work be thrown upon this organ, too, its function becomes disordered, from its inability to separate from the blood all that it should draw off; the injurious substances accumulate in the blood, therefore, producing various symptoms that are known under the general term of *bilious;* and to get rid of these, it becomes necessary to administer medicines (especially those of a mercurial character) which shall excite the liver to increased secretion. The constant use of these medicines has a very pernicious effect upon the constitution, and careful attention to the regulation of the diet, and especially the avoidance of a superfluity of oily or farinaceous matter, will answer the same end in a much better manner.

351. That the materials of the biliary and urinary excretions exist (like the carbonic acid thrown off by respiration) ready formed in the blood, being taken up by it in the course of its circulation,—and that the function of the Liver and Kidneys is (like that of the Lungs in regard to carbonic acid) to *separate* them, and not to form them,—has now been fully proved. The quantity of them present in the circulating fluid, however, is usually very small; for the simple and obvious reason that, if the excreting organs are in a state of healthy activity, these substances are drawn off by them from the blood, as fast as they are introduced into it. But if the excretions are checked, they speedily accumulate in the blood, to such a degree, as to be easily detected by the Chemist, and also to make their presence evident by their effects upon the animal functions, especially those of the nervous system. This sometimes happens in consequence of

disease, and it may be imitated by experiment; for when the trunk of the blood-vessel, conveying the blood to the liver or kidney, is tied, the excretion is necessarily checked, and the same results take place as when the stoppage has resulted from want of secreting power. The biliary and urinary matters have the effect of narcotic poisons upon the brain; when they have accumulated in the blood, their symptoms begin to manifest themselves; and they increase in intensity, as the amount of these substances is augmented, until death takes place.

352. It is unnecessary to say more then, to prove the great importance of the functions of *Excretion* in the Animal Economy; and the necessity of carefully attending to them. The various *Secretions* which are formed in different parts of the body, have not so much for their object the purification of the blood, as certain purposes which are to be answered by them in the animal economy. Thus we find the Salivary and Gastric fluids poured into the mouth and stomach, for the reduction and solution of the food (§. 190 and 204); the Lachrymal secretion poured out upon the surface of the eye, for the purpose of washing it from impurities (§. 540); the secretion of Milk in Mammalia, for the nourishment of the young; and various poisonous secretions in Serpents and Insects, for the destruction of their prey or for means of defence. Any one of these may be checked, without rendering the blood impure by the accumulation of any substances that should be drawn off from it; but its cessation may produce effects fully as injurious, by disordering the function to which it is subservient. Thus, if the salivary and gastric secretions were to cease, the reduction of the food could not be effected, and the animal must starve, though its stomach were filled with wholesome aliment. It is to be observed in regard to nearly all these secreted fluids, that they contain but a small quantity of solid matter, and that this matter strongly resembles the ordinary constituents of the blood, especially albumen. Hence we may believe that these secretions are formed by the several organs which elaborate them; and that they do not pre-exist as such in the blood.

353. The various acts of Secretion and Excretion which are

continually taking place in the living body, are, like those of Nutrition, completely removed from the influence of the *will;* but they are strongly affected by *emotions* of the mind. This has been already pointed out in regard to the saliva (§. 190); and it is equally evident in the case of the lachrymal secretion (§. 540). In these instances, however, the effect of the emotion is manifested upon the *quantity* only of the secretion; in the case of the secretion of Milk, not only the quantity but the *quality* is greatly influenced by the mental state of the nurse. The more even her temper, and the more free from anxiety her mind, the better adapted will be her milk for the nourishment of her offspring. There are several instances now on record, in which it has been clearly shown, that the influence of violent passions in the mother has been so strongly exerted upon the secretion of milk, as almost instantaneously to communicate to it an absolutely poisonous character, which has occasioned the immediate death of the child.* The influence of the emotions upon the Secretions is probably communicated by the Sympathetic system of Nerves (§. 461), which is very minutely distributed, with the blood-vessels, to the several glands which form them.

Nature of the Secreting Process.—Structure of the Secreting Organs.

354. Notwithstanding the different characters of the products of Secretion and Excretion, and the variety of the purposes to which they are destined to be applied, the mode in which they are elaborated or separated from the blood is essentially the same in all. The process is performed, in the Animal, as in the Plant, by the agency of *cells;* and the variety of the structure of the different *glands*, or secreting organs, has reference merely to the manner in which these, their essential parts, are arranged. The simplest condition of a secreting cell, in the animal body, is that in which it exists in Adipose or fatty tissue; which is composed, as formerly explained (§. 44), of a mass of cells, bound together by areolar tissue, which allows the blood-vessels to gain access

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* See the Author's Principles of Human Physiology, Chap. VII.; and Dr. A. Combe on the Management of Infancy, Chap. X.

to them. Every one of these cells has the power of secreting or separating fatty matter from the blood; and the secreted product remains stored up in its cavity, as in Plants (VEGET. PHYS. §. 361)—not being poured forth, as it is in most other cases, by the subsequent bursting of the cell.

355. But when the secreting cells are disposed on the surface of a membrane, instead of being aggregated in a mass, it is obvious that, if they burst or dissolve away, their contents will be poured into the cavity bounded by that membrane; and this is the mode in which secretion ordinarily takes place. Thus, the *mucous membranes* (§. 38) are covered with *epithelium-cells*, which have the power of separating the peculiar glairy viscid substance termed *mucus*, from the blood which is distributed to the membrane beneath them. They are continually being cast off, and are replaced as constantly by a fresh crop of cells, developed from germs contained in that membrane; and the cells of each crop, as they are cast off, pour forth their contents, which thus cover the whole surface of the membrane with a layer of viscid fluid, that serves for its protection. In parts of the membrane where it is necessary that the secretion should be peculiarly abundant, we find its secreting surface greatly increased, by being prolonged into vast numbers of little pits or bags, termed *follicles*, which are lined with epithelium-cells, that resemble those of its general surface (see Fig. 2). These epithelium-cells, in the progress of their development, draw into themselves certain products from the blood; and when they have attained their full growth, they are cast off, and pour forth their contents, either by dissolving away, or by bursting. Such follicles are very abundant along the whole alimentary canal of Man; and there is good reason to believe that a new crop of cells is developed in them, every time that the digestive process takes place (§. 39).

356. Now, although the most important Secretions and Excretions are elaborated, in Man and the higher animals, by organs of a much more complex structure, yet in the lower we find them produced by *follicles*, which are formed exactly upon this plan. Thus in the little *Bowerbankia*, (§. 134) the bile is secreted by minute follicles which are lodged in the walls of the

stomach (Fig. 77, *c*), and pour their secretion separately into its cavity, having no communication with one another. The glandular apparatus which surrounds the alimentary canal in the Wheel-Animalcule (Fig. 59, *h*, *h*) seems to be made up of similar follicles, having separate openings into the cavity. In more complex forms of the same organ, however, several follicles open together into a tube, which either pours its contents directly into the alimentary canal, or unites with other tubes to do so. The condition of such a glandular organ very much resembles that of a bunch of grapes; as is seen in Fig. 158, which represents the structure of the Parotid gland (one of the salivary glands) of Man. The main stalk is the duct into which all the others enter; from this pass off several branches, and these again give off smaller twigs, the extremities of which enter the minute follicles in which the secretion is formed. These follicles are lined, as in their simple condition, with cells, which are the essential instruments in the production of the secretion; the fluid which they separate is poured, by the giving way of their walls, into the small canals proceeding from the follicles, thence into the larger branches, and finally into the main trunk, by which it is carried into the situation where it is to be employed or from which it is to pass out. The Liver will be seen to possess a structure exactly resembling this, in the Crustacea, by referring to Fig. 48 (*fo*); and in the Mollusca it is nearly the same (Figs. 14, *l*, and 142, *f*).

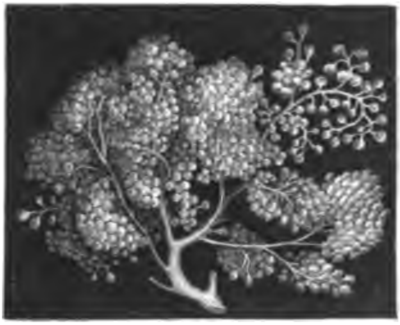

FIG. 158.—INTIMATE STRUCTURE OF A COMPOSITE GLAND (THE PAROTID).

357. The required extent of secreting surface is not unfrequently given, however, by the prolongation of the follicles into tubes, rather than by a great multiplication in their number. Of

this we have a remarkable example in the Kidney of the higher animals, which is entirely composed of such tubes, and of the blood-vessels distributed amongst them. If we make a vertical section of the kidney of Man or any of the higher Mammalia, (Fig. 159, A) we find that it seems composed of two different substances, one surrounding the other; to the outer, *a*, the name of *cortical* (bark-like) substance has been given; whilst the inner, *b*, is termed *medullary* (or pith-like). In the cortical substance, no definite arrangement can be detected by the naked eye; it chiefly consists of a very intricate network of blood-vessels, surrounding the extremities of the tubes. But in the medullary substance we can trace a regular passage of minute tubes, from the circumference towards the centre. They commence in the midst of the network of blood-vessels (B, *a*), and then pass down in clusters, nearly in a straight direction, and slightly converging towards each other, until each cluster terminates in a little body, called the *calyx* or cup, which discharges the fluid it receives into the large cavity of the kidney, termed the *pelvis*, or basin (A, *c*). From this it is conveyed away by the ureter, *d*.—These tubes, like the follicles, are lined with epithelium-cells, which are the real instruments in the production of their secretion.

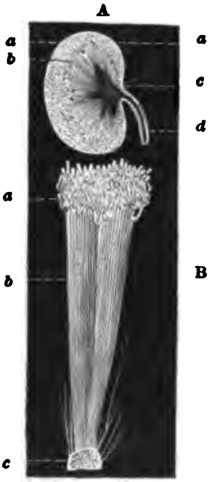

FIG. 159.—STRUCTURE OF THE KIDNEY OF MAN.

A, vertical section of the kidney, *a*, cortical substance; *b*, tubular substance; *c*, calyx and pelvis; *d*, the ureter.

B, portion of the gland enlarged; *a*, extremity of the uriniferous tubes; *b*, straight portion; *c*, their termination in the calyx.

358. That there is nothing in the *form* of the secreting apparatus, however, which determines the peculiar nature of its secretion, is evident from this fact,—that, in glancing through the Animal series, we find the same secretion elaborated by glandular structures of every variety of form. Thus, we have seen that the *bile* is secreted, in the lowest animals in which we can distinguish it, by a number of distinct follicles, as simple in their structure

as are those by which the mucous secretions are formed in the highest. But in Insects, the bile is secreted by a small number of long tubes, which open into the intestinal canal just below the stomach (Fig. 110); and these tubes apparently differ in no respect from those that form the urinary secretion in the same animals, which open nearer the outlet of the intestinal canal. In fact, the distinct function of the latter was not known, until it was ascertained that uric acid is to be found in them. In Fig. 160, which represents the digestive apparatus of the Cock-chafer, it is seen that the biliary vessels are only four in number, but are very long; and that, for a good part of their length, they are beset with a series of short tubes opening from them, by which the extent of secreting surface is much increased.—On the other hand, although the *urinary* secretion is generally formed by long tubes, yet in the Mollusca it is secreted by follicles, according to the general plan of their glandular structures.

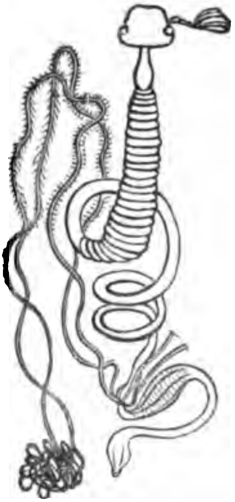

FIG. 160.—DIGESTIVE APPARATUS OF COCK-CHAFER.

359. The secreting cells not unfrequently possess the power of elaborating a peculiar colouring matter, either separately, or along with the substances which seem more characteristic of the secretion. Thus the *ink* of the Cuttle-fish is in reality its urine, charged with a quantity of black matter formed in the pigment-cells (§. 533) that line its ink-bag; and the corresponding secretion in other Mollusca is rendered purple by the same cause. The bile seems to be universally tinged with a yellow colouring matter, which may be regarded, therefore, as an essential part of the secretion; in some herbivorous quadrupeds it has a green hue, and the colouring matter by which this is given, appears to be identical with that contained in the vegetable tissues on which they feed.

360. It appears, then, that the different secreting cells have the power of elaborating a great variety of products; and that no essential differences can be discovered in the structure of the glands into whose composition they enter, which can account for that variety. We are entirely ignorant, therefore, of the reason why one set of cells should secrete biliary matter, another urea, another a colouring substance, and so on; but we are *as* ignorant of the reason why, in the parti-coloured petal of a flower, the cells of one portion should secrete a red substance, whilst those in immediate contact with it form a yellow or blue colouring matter; and we know *as* little of the cause, which occasions one set of the cells of which the embryo is composed, to be converted into muscular tissue, another into cartilage, and so on. Although, therefore, there is a limit to our knowledge, beyond which it does not at present seem probable that we shall ever pass, it is an important step to have attained the general principle, that, in Animals as in Plants, the process of secretion is performed by *cells;* the difference being that, in the latter, the secreted products remain, for the most part, stored up within the cells, which form part of the general fabric; whilst in the former, the secreting cells are generally subject to continual death and renewal, so as to cast the products they have elaborated, into channels, by which they may be carried out of the body. But the *fat* of Animals, as already mentioned (§. 44), is an instance of a mass of secreting cells remaining unchanged in the midst of the body.

361. One of the most curious points in the Physiology of Secretion, is the interchange which sometimes occurs in the functions of particular glands. When the operation of some one gland is checked or impaired by disease, it not unfrequently happens that another gland, or perhaps only a secreting surface, will perform its functions more or less perfectly; this happens most frequently in regard to the important Excretions, as if Nature had especially provided for their continued separation from the blood, that its purity may be unceasingly maintained. Thus the urinary secretion has been passed off from the surfaces of the skin, stomach, intestines, and nasal cavity, and also from the mammary gland; the colouring matter of the bile, when it

accumulates in the blood (as in jaundice) is separated from it in the skin and conjunctival membrane of the eye (§. 537); and milk has been poured forth from pustules on the skin, and from the salivary glands, kidneys, &c. Such cases have been regarded as fabulous; but they rest upon good authority, and they are quite consistent with physiological principles. For a little consideration will show that, as the membrane which lines the stomach and intestinal tube is but a prolongation of that which forms the external surface of the body (§. 14), so the membrane that lines the tubes and follicles of which the glands are composed, is but a prolongation or extension of the former. Now we have seen that, in the lowest animals, the lining membrane of the stomach, and that which covers the surface, may be made to take the places of each other, without detriment to their respective operations (§. 14); and it is not incredible, therefore, that the various divisions of the secreting surface, which ordinarily have separate duties to perform, should be able, under particular circumstances, to take on, to a certain degree, each other's functions.

362. Some of the main ducts or channels, through which the glands pour forth their secretions, are provided with enlargements or receptacles, which serve to retain and store up the fluid for a time, until it may be desirable or convenient that it should be discharged. Thus, in most of the higher animals, the duct which conveys into the intestinal tube the bile secreted by the liver, is also connected with a receptacle termed the *gall-bladder;* the bile, as it is secreted, passes into this, and is retained there until it is wanted for assisting in the digestive process (§. 212); when it is pressed out into the intestinal canal. It is a curious fact, that in most persons who die of starvation, the gall-bladder is found distended with bile; showing that the secretion has continued, but that it has not been poured into the intestine for want of the

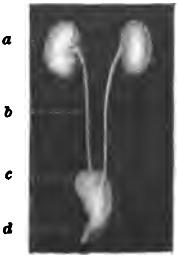

FIG. 161.—URINARY APPARATUS.
a, kidneys; b, ureters; c bladder; d, its canal, the urethra.

stimulus occasioned by the presence of food in the latter. In many quadrupeds, especially those of the Ruminant tribe, the milk-ducts are in like manner dilated into a large receptacle, the udder, which retains the secretion as it is formed, until the period when it is needed. In all Mammalia, and in some Reptiles, Mollusca, and Insects, but not in Birds or Fishes, we find the *ureters*, which convey away the urinary excretion, dilated at their lower extremity into a bladder (Fig. 161), which serves to retain all the fluid that is poured forth by the gland during a considerable length of time, and thus to prevent the necessity for its being continually passed out of the body.

Characters of Particular Secretions.

363. In regard to the particular characters of the various secretions, and the structure of the organs by which they are respectively formed, it would be unsuitable to the character of the present work to enter into any detail; but it will be desirable to notice some of the more important circumstances connected with the chief of them.

364. The *Bile*, which is secreted by the Liver, is characterised, as already stated (§. 346), by the presence of a large quantity of fatty and other matters, which are chiefly composed of carbon and hydrogen. It is difficult to determine the exact characters of these; but it seems pretty certain that one of them, at least, is a crystallisable fatty substance, somewhat resembling spermaceti; this, to which the name of *Cholesterine* has been given, contains 37 equivalents of carbon, and 32 of hydrogen, with only one of oxygen, and no azote. Now the proportional amount and importance of this excretion seem to vary considerably in different classes of animals. In all, it appears to be concerned in the operation of digestion (§. 212); for we always find it poured into the alimentary canal, near the stomach, instead of being carried directly out of the body, like the urinary excretion. But whilst in some instances this seems to be almost its only function, in others it appears to have for its purpose to carry out of the system a large quantity of carbon and hydrogen, of which the respiratory apparatus cannot get rid.

365. It is a general rule, to which there are few if any exceptions, that the development and activity of the Respiratory organs and of those concerned in the secretion of Bile, stand in an inverse proportion to one another, through the whole animal series. Thus we find in Insects, a respiratory system possessing enormous extension and activity of function, and a liver so slightly developed, that for a long time it was not recognised as such. On the other hand, in the Mollusca, we find the respiration carried on upon a lower plan, and with far less activity; but the liver is of enormous size (often making up a large part of the bulk of the body), and its secreting power is evidently very great. Moreover, in the Crustacea, which are formed upon the same general plan with Insects, but which have an aquatic and therefore less energetic respiration, we find the liver very large, as in the Mollusca. In Reptiles and Fishes, again, whose respiration and temperature are low, the liver is comparatively larger than in Birds and Mammalia, in which classes the respiration is more energetic, and the blood warm. And finally, in the embryo of the latter, whose respiration is very imperfect, the liver is much larger, in proportion, than it is in the adult;* its weight in the new-born child being about 1-18th that of the body, whilst in the adult it is not more than 1-36th. Hence the conclusion seems almost indisputable, that the superfluous carbon and hydrogen of the body are chiefly carried off by the Respiratory organs, when it is required that the temperature of the body should be high, and that oxygen should be introduced into the system in large amount; but that the office of excreting them devolves upon the Liver, when there is no necessity for keeping up the heat of the body, or for making the excretion the means of introducing oxygen (§. 307).

366. It is a remarkable point in reference to the secretion of Bile, that, in all the Vertebrata, it is formed from *venous* blood. The veins of the intestines and glands connected with them, as also in Fishes the veins from the tail and hinder part of the body,

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* These facts appear to the Author to furnish an important objection to the doctrine of Liebig, as to the connexion between the secretion of bile and the respiratory process.

unite into a trunk, the *vena portæ* (§. 266), which might almost be considered an artery, for it conveys the blood *to* the liver, and then subdivides into a set of minutely-divided capillaries, by which the fluid is carried into every part of the substance of the gland. From this venous blood, the secretion of bile is formed; and it is not elaborated from the arterial blood that is sent to the liver for its nourishment, until this has passed through the capillaries—in which it is rendered venous. Hence it may be inferred that the materials from which the bile is formed, peculiarly exist in *venous* blood, which has become charged, whilst passing through the capillaries, with the products of their decomposition, and needs to be purified from these.

367. The *Urinary* excretion has for its chief purpose to throw off those products, formed in a similar manner, which are highly charged with azote. The most important of its ingredients, in Man and the Mammalia, is the substance termed *Urea*, which has a crystalline form, and is very soluble in water. It contains 2 equivalents of Carbon, 4 of Hydrogen, 2 of Azote, and 2 of Oxygen; and it will be seen, by referring to the statement formerly given (§. 21) of the proportions between the elements of albumen and gelatin, that the amount of azote in proportion to that of the other elements is much greater in urea than it is in these substances, which form the materials of the animal tissues. The quantity of Urea which is daily excreted is very considerable, the average in an adult being about an ounce, and in a child of 8 years old about half as much. There is another compound which does not usually exist in large amount in the urine of the Mammalia, but which makes up a considerable part of the solid matter of this secretion in Birds and the lower Vertebrata; this is *uric* or *lithic* acid, which consists of 10 equivalents of Carbon, 4 of Hydrogen, 4 of Azote, and 6 of Oxygen. It is almost entirely insoluble in water, unless it is combined with ammonia; and in this state it ordinarily exists. When formed in too large quantity, however, it may be deposited in an insoluble form, constituting gravel (§. 348); and the same effect may result from the presence of some other acid, which, combining with the ammonia, precipitates or sets free the

lithic acid; thus a gravelly deposit may be found in the urine, when no undue amount of uric acid has been secreted, simply because, by disordered digestion and nutrition, there is an improper formation of lactic acid in the stomach, or in the blood, which precipitates the lithic acid in the urine.

368. One of the most interesting circumstances in reference to the Urinary secretion, is the very large quantity of water which, in the higher animals, is thus got rid of; and the means by which this is accomplished. The kidneys seem to form a kind of regulating valve, by which the quantity of water in the system is kept to its proper amount. The exhalation from the skin, which is the other principal means by which this is effected, is liable to sustain great variations in its amount, from the temperature of the air around; for when this is low, the exhalation is very much diminished; and, when it is high, the quantity of fluid that passes off in this manner is increased (§. 371). Hence if there were not some other means of adjusting the quantity of fluid in the blood-vessels, it would be liable to continual and very injurious variation. This important function is performed by the kidneys, which allow such a quantity of water to pass into the urinary tubes, as may keep the pressure within the vessels very nearly at a uniform standard. Hence the quantity of water in the urinary secretion depends in part upon the amount exhaled from the skin,—being greatest when this is least, and *vice versâ*;—and in part upon the quantity which has been absorbed by the vessels. The quantity of solid matter in the secretion has but little to do with this; for it depends upon the amount of waste of the muscular and other tissues that has been occasioned by their activity (§. 160); and also upon the quantity of surplus aliment, which is discharged through this channel, there being no other vent for it (§. 348).

369. The solid matter of the urine is elaborated, like that of other secretions, by the cells lining the tubes. But in animals which pass off a large quantity of *water* through this organ, there is a distinct and very curious provision for its separation. The extremity of the uriniferous tube is made to include a little knot or bunch of capillary vessels, which have extremely thin

walls; and a vast number of such knots are scattered through the cortical portion (§.357) of the kidney. To these the blood which is brought to the organ by the renal artery, is first conveyed; and the membranes that separate the interior of the capillary vessels from the cavity of the uriniferous tube, being of extreme thinness, water is readily able to traverse them; and will do so in larger or smaller quantity, according as the pressure upon the walls of the capillaries is greater or less. The blood which has passed through these is next conducted to another set of capillaries, which form a net-work upon the part of the tube that is lined by the secreting cells; and it is there subservient to the elaboration of the solid part of the secretion, which is afterwards set free in the cavity of the tube, by the bursting of the cells, and is then dissolved in the fluid which has already found its way into the tube.

370. Next to the excretions formed by the liver and the kidneys, that of the Skin probably ranks in importance. A large quantity of watery vapour is constantly passing off from the whole surface of Man and other soft-skinned animals; and this amount is greatly increased under particular circumstances. It will be remembered that, in Plants, a distinction was drawn between the simple *evaporation* of fluid, which takes place from the necessary action of the dry air upon the soft moist surface, and which would continue to take place from the similar surface of a dead plant,—and the *exhalation*, which was described as a special function, performed by the living plant only, and dependent as to its activity on the amount of light it is exposed to. (VEGET. PHYS. §§. 254—259). Precisely the same difference exists in Animals. A continual evaporation is taking place from the surface of the skin, wherever it is not protected by hard scales or plates; and the amount of it will depend upon the warmth, dryness, and motion of the surrounding air, exactly as if the fluid were being evaporated from a damp cloth. Every one knows that the drying of a cloth is much more rapidly effected in a warm dry atmosphere, than in a cold moist one; more quickly, too, in a draught of air, than in a situation where there is no current, and where the air is consequently soon

charged with moisture. That all these influences affect the evaporation from the bodies of Animals, there is ample evidence derived from experiment.

371. But besides this continual evaporation, there is another mode in which loss of fluid takes place from the surface of the body. A vast number of minute glands are imbedded in the fatty layer just beneath the skin, and are copiously supplied with blood by its vessels; their ducts pass through it, twisting in a spiral manner, towards its surface, where they open; their orifice being covered by a little valve or flap of the epidermis (§. 35) which the fluid lifts up, when it is poured forth by the canal. These perspiratory glands seem to be continually exhaling fluid, which is dissolved by the atmosphere and carried off in the state of vapour, so as to pass away *insensibly;* but they are stimulated to increased action by the exposure of the body to *heat*, which causes them to pour forth their secretion in greater abundance than the air can carry off, and this consequently accumulates in drops upon the surface of the skin. The amount of perspiration may be considerably increased, without its becoming *sensible*, if the air be warm and dry, and is thus able to carry off, in the form of vapour, the fluid which is poured out on the skin; but, on the other hand, a very slight increase in the ordinary amount immediately becomes sensible on a damp day, the air being already too much loaded with moisture to carry off this additional quantity. The distinction between *insensible* and *sensible* perspiration, is not the same, therefore, with the difference between simple *evaporation* and *exhalation* from the skin; for a part of the latter is commonly insensible; and the degree in which it is so, depends upon the amount of fluid exhaled, and the state of the surrounding atmosphere. If the fluid thus poured forth be allowed to remain upon the surface of the skin, it produces a very oppressing effect; most persons have experienced this, when walking in a macintosh cloak or coat, on a damp day. The water-proof garment keeps *in* the perspiration, almost as effectually as it keeps *out* the rain; and consequently the air within it becomes loaded with

fluid, and the skin remains in a most uncomfortable as well as prejudicial state of dampness.

372. Although no evaporation from the skin can take place when the surrounding atmosphere is loaded with vapour, the secretion of the perspiratory glands continues; and does so even when the skin is immersed in fluid, provided the fluid be of high temperature. Hence we see that the conditions under which it is poured forth are peculiar to the living body alone, and entirely differ from those under which simple evaporation takes place. The purpose of this watery exhalation, and of its increase under a high temperature, is evidently to keep the heat of the body as near as possible to a uniform standard. By the evaporation of fluid from the surface of the skin, a considerable quantity of heat is withdrawn from it, becoming *latent* in the change from fluid to vapour;* of this we make use in applying cooling lotions to inflamed parts. The more rapid the evaporation, the greater is the amount of heat withdrawn in a given time; hence, if we pour, on separate parts of the back of the hand, a small quantity of ether, alcohol, and water, we shall find that the spot from which the ether is evaporating feels the coldest, that which was covered by the alcohol less so, whilst the part moistened with water is comparatively but little chilled. The greater the amount of heat applied to the body, then, the more fluid is poured out by the perspiratory glands; and as the air can carry it off more readily in proportion to its own heat, the evaporation becomes more rapid, and its cooling effect more powerful. It is in this manner that the body is rendered capable of sustaining very high degrees of external heat, without suffering injury. Many instances are on record, of a heat of from 250° to 280° being endured in dry air for a considerable length of time, even by persons unaccustomed to a peculiarly high temperature; and individuals whose occupations are such as to require it, can sustain a much higher degree of heat, though perhaps not for any great length of time. Thus, the workmen of the late Sir F. Chantrey were accustomed to enter a furnace in which his moulds were dried, while the floor was red-hot,

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* See Treatise on HEAT.

and a thermometer in the air stood at 350°; and Chabert, the "Fire-king," was in the habit of entering an oven, whose temperature was from 400° to 600°. It is possible that these feats might be easily matched by many workmen, who are habitually exposed to high temperatures; such as those employed in iron-foundries, glass-houses, and gas-works.

373. That the power of sustaining a high temperature mainly depends upon the dryness of the atmosphere, is evident from what has been just stated; since, if the perspiration that is poured forth upon the skin is not carried off with sufficient rapidity, on account of the previous humidity of the air, the temperature of the body will not be sufficiently kept down. It has been found, from a considerable number of experiments, that when warm-blooded animals are placed in a hot atmosphere, saturated with moisture, the temperature of their bodies is gradually raised 12° or 13° above the natural standard; and that the consequence is then inevitably fatal.

374. The amount of fluid exhaled from the skin and lungs (§. 343) in twenty-four hours probably averages about three or four pounds. The largest quantity ever noticed, except under extraordinary circumstances, was 5 lbs.; and the smallest $1\frac{2}{3}$ lbs. It contains a small quantity of solid animal matter, besides that of the other secretions of the skin which are mingled with it; and there is good reason to think that this excretion is of much importance, in carrying off certain substances which would be injurious if allowed to remain in the blood. That which is called the Hydropathic system proceeds upon the plan of increasing the cutaneous exhalation, to a very large amount; and there seems much evidence, that certain deleterious matters, the presence of which in the blood gives rise to Gout, Rheumatism, &c., are drawn off from it more speedily and certainly in this way, than in any other.

375. Besides the perspiratory glands, the skin contains others, which have special functions to perform. Thus in most parts which are liable to rub against each other, we find a considerable number of *sebaceous* follicles, which secrete a fatty

substance that keeps the skin soft and smooth.* These are abundant on the most exposed parts of the face; and their secretion prevents the skin from drying up and cracking, which it would be liable to do under the influence of the sun and air. They are more numerous in the skins of Negroes, producing in them that oily sleekness for which they are generally remarkable, and which prevents their skins from suffering by exposure to a tropical sun, as would those of Europeans. Besides the sebaceous follicles, the skin contains others in particular parts, for secreting peculiar substances; as, for instance, those which form the *cerumen*, or bitter waxy substance that is poured into the canal leading to the internal ear, for the purpose (it would seem) of preventing the entrance of insects.

376. The secretion of *Milk* is important, not so much to the parent who forms it, as to the offspring for whose nourishment it is destined. It does not seem to carry off from the system any injurious product of its decomposition; for it bears a remarkable analogy to blood in the combination of substances which it contains; nevertheless it is found that, when this secretion is once fully established, it cannot be suddenly checked, without producing considerable disturbance of the general system. The structure of the mammary gland closely resembles that of the parotid, already described (§. 356). It consists of a number of lobules, or small divisions, closely bound together by fibrous and areolar tissue; to each of these proceeds a branch of the milk-ducts, together with numerous blood-vessels; and the ultimate ramifications of these ducts terminate in a multitude of little follicles, like those shown in Fig. 158, and about the size (when distended with milk) of a hole pricked in paper by the point of a very fine pin.

377. The nature of the secretion of milk is made evident by the processes to which we commonly subject it. When allowed to stand for some time, the *oleaginous* part, forming the *cream*, rises to the top. This is still combined, however, with a certain

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* It has lately been discovered that, even in persons of cleanly habits, each of these follicles is the residence of a minute insect closely resembling the cheese-mite.

quantity of albuminous matter, which forms a kind of envelope round each of the oil-globules. In the process of churning, these envelopes are broken; and the oil-globules run together into a mass, forming *butter*. In ordinary butter, a certain quantity of albuminous matter remains; which, from its tendency to decomposition, is liable to render the butter rancid; this may be got rid of by melting the butter at the temperature of 180°, when the albumen will fall to the bottom, leaving the butter pure, and much less liable to change. In making *cheese*, we separate the *albuminous* portion, or *casein*, by adding an acid, which coagulates it. The buttermilk and whey left behind after the separation of the other ingredients, contain a considerable quantity of sugar, and some saline matter. The proportion of these ingredients varies in different animals; and also in the same animal, according to the substances upon which it is fed, and the quantity of exercise it takes (§. 164). The amount of *casein* seems to be greatest in the milk of the Cow, Goat, and Sheep; that of *oleaginous* matter in the milk of the Human female; and that of *sugar* in the milk of the Mare. The milk of the Cow, if a portion of its casein were removed, would resemble Human milk more nearly than any other; and it is therefore best for the nourishment of Infants, when the latter cannot be obtained. The important influence of mental emotion on this secretion has already been noticed (§. 353); and many more instances might be related, were not the ordinary facts in regard to it generally known.

CHAPTER VIII.

GENERAL REVIEW OF THE NUTRITIVE OPERATIONS.—FORMATION OF TISSUES.

General Review of the Nutritive Operations.

378. IN the preceding Chapters (III. to V.) those processes have been described, by which the alimentary materials, that constitute the *raw material* of the tissues, are converted into a fluid adapted for the Nutrition of the body; and we then (CHAPS. VI. and VII.) considered those functions, by which this fluid is kept free from the impurities it acquires during its circulation through the body, and is maintained in the state which alone can adapt it to the purposes it is destined to fulfil. These purposes may be regarded as fourfold. In the *first* place, the Blood is destined to supply the materials of the fabric of the body; which, as it is continually undergoing decay (§. 54), requires the means of as constant a renovation. *Secondly*, the Blood (in most animals at least) serves to convey to the tissues the supply of oxygen which is required by them—especially by the muscular and nervous tissues,—as a necessary stimulus to the performance of their functions. *Thirdly*, the Blood furnishes to the secreting organs the materials for the elaboration of the various fluids, which have special purposes to serve in the Animal economy,—such, for instance, as the Saliva, Gastric Juice, Milk, &c. And *lastly*, the Blood takes up, in the course of its circulation, the products of the *waste* or decomposition of the various tissues, which it conveys to the various organs,—the Lungs, Liver, Kidneys, &c.,—destined to throw them off by Excretion. The greater number of these processes have already been treated of in more or less detail. Those included under the first head

were considered, in a general form, in Chap. I. of this Treatise. Those which are comprehended under the second head have been dwelt on in Chaps. V. and VI.; and will be again noticed, when the actions of the Nervous and Muscular tissues are described. And the varied actions which are included under the third and fourth classes, have been discussed in the two Chapters which precede the present one.

379. We have now to enter, in more detail, into the mode in which the circulating fluid is applied to the Nutrition and Formation of the Tissues; but, before proceeding to this, it will be advantageous to recapitulate briefly the properties of this fluid, and to compare them with those of the various kinds of structure into which its elements are to be converted.

380. The circulating blood of Vertebrata consists of a clear fluid, the *liquor sanguinis*, in which float a vast number of *red corpuscles* (§. 229). As these last, however, are not present in Invertebrated animals, it is evident that they cannot be essential to the *nutritive* operations to which the Blood is subservient; and strong reasons have been given for the belief, that they minister to the *respiratory* operations, by which oxygen is carried through the capillary vessels into every part of the system, and carbonic acid is, in like manner, conveyed away from them, to be set free in the lungs (§. 234). In considering the nutrition and formation of the tissues, therefore, we may probably leave the *red* corpuscles out of view. The *liquor sanguinis* contains the two animal substances, *fibrin* and *albumen*, in a state of solution; together with fatty matter and saline substances; and, from some recent inquiries, it would seem to contain *gelatin* also, or, at least, a substance which may be easily converted into gelatin by long boiling.

381. The *Albumen* of the blood is derived at once from the food; for it is in this form that all the albuminous portion of the aliment is received into the system, having been reduced to this condition by the digestive process, whatever may have been its previous character (§. 16); and it serves as the raw material, from which the other products are elaborated. Most of the animal Secretions contain a greater or less amount of albuminous matter (§. 352); but there is no sufficient evidence that albumen,

as such, ever enters into the composition of the Animal *Tissues*.* In fact it appears to be incapable of undergoing organisation, until its condition has been changed into that of *Fibrin*. The formation of this last substance appears to be continually taking place, during the motion of the circulating fluid through the living vessels. It is evidenly derived from the albumen derived from the food; and it is probably elaborated by the colourless floating cells, which are found both in the chyle and in the blood of Vertebrata, and which exist in the blood of the Invertebrated animals (§. 235, 241). That this Fibrin is the material, at the expense of which the organised fabric is chiefly if not entirely formed, seems highly probable, from a variety of considerations formerly touched upon. It passes spontaneously, in the act of *coagulation* (§. 18), into a regular fibrous tissue of simple structure; and all that seems necessary for the complete *organisation* of this, is that it should be permeated by vessels, which may furnish it with the materials of its growth and renovation. We shall presently find that the formation of blood-vessels takes place, in all instances, *subsequently* to the first production of a tissue, and is consequently not essential to it (§. 392).

382. It has been shown (Chap. I.) that the tissues which originate in this manner, are those which have functions simply *mechanical*,—such as affording support, resisting strains, or imparting elasticity. But the tissues which possess endowments peculiarly *vital*,—that is to say, entirely different from the physical properties of inorganic matter, and manifested only by a living organised tissue,—are formed in a different manner; being either permanently composed of cells, or having their origin in them, and undergoing a subsequent transformation. We have seen, in preceding chapters (IV. and VI.), that the selection of alimentary materials from the chyme, and their introduction into the blood, is accomplished by the agency of *cells*, which rapidly grow, and disappear again as rapidly; and that the selection from the blood of the materials of the secretions is accomplished in the same manner. These

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* Physiologists have been accustomed to speak of the *albuminous* tissues; but the Author believes that he is justified in asserting, that no *chemical* difference exists, by which albumen and fibrin can be certainly distinguished.

processes are of a nature peculiarly *vital;* as we cannot imagine them to be in any way dependent upon the *physical* properties of matter; the same may be said of the agency of the floating cells of the chyle and blood, in converting albumen into fibrin; and of the red corpuscles in elaborating, from the fluid which surrounds them, the peculiar substance they contain. All these processes have reference only to the nutritive actions, or *organic life* (§. 4) of the being; and their essential nature is the same, as we have already seen, in the Plant and in the Animal. There is this interesting circumstance to be observed in regard to them,—that the action of every cell is independent of that of its fellows, yet that by the wonderful adaptation of their several properties (of which we can give no account whatever, except that it is the will of the Creator), they all work together for one general end, the maintenance of the bodily fabric.

383. On the other hand, the Muscular and Nervous tissues, which are subservient to the actions of *animal* life, although originally formed from cells, have a very different structure when complete. It is easy to see that, so long as cells remain isolated from each other, they exist as so many distinct individuals,—performing, it may be, the very same operations,—but doing this independently of one another. Now the very nature of the animal functions requires, that the actions of the several parts of the tissues which perform them, should be most intimately connected; thus, when an impression is made upon any part of the surface of the body, it has to be *instantaneously* communicated to the brain; or an effort of the will, acting through the brain, has to call into *immediate* operation a large amount of muscular tissue. We could not conceive these functions to be performed by a number of isolated cells; and we find, in fact, that the muscular and nervous tissues are composed of *tubes*, containing substances that are peculiar to each respectively (§. 428 and 578). These tubes originate, like the *ducts* of plants (VEGET. PHYS. §. 82), in cells laid together end to end, the partitions between which have broken down; and the deposits that are found within them, on which their peculiar properties seem to depend, are formed at a subsequent time.

Formation of the Tissues.

384. We see, then, that all the Animal tissues may be considered as taking their origin in fibrin,—either *directly* in the fibrous network formed by its coagulation, or *indirectly* in the cells which are developed at its expense. The question next arises,—what is the origin of these cells?

385. There is sufficient reason to believe that every living being is developed from a *germ;* no organised structure being able to take its origin (as some have supposed) in a chance combination of inorganic elements. All the facts relating to the production of Fungi and Animalcules, which have been imagined to favour this doctrine, may be satisfactorily explained in other ways (VEGET. PHYS. §. 50, 51). Now the first structure developed from this germ, in the Animal as in the Plant, is *a simple cell;* and the entire fabric subsequently formed, however complex and various in structure, may be considered as having had its origin in this cell. The cells of Animals, like those of Plants, multiply by the development of new cells within them; each of these becomes in its turn the parent of others; and thus, by a continuance of the same process, a mass consisting of any number may be produced from a single one. It is in this manner that the first development of the Animal embryo takes place, as will be shown hereafter (Chap. xv). A globular mass, containing a large number of cells, is formed before any diversity of parts shows itself; and it is by the subsequent development, from this mass, of different sets of cells,—of which some are changed into cartilage, others into nerve, others into muscle, others into vessels, and so on,—that the several parts of the body are ultimately formed. Of the cause of these transformations, and of the regularity with which they take place in the different parts, according to the type or plan upon which the animal is constructed, we are entirely in the dark; and we may probably never know much more than we do at present.

386. When once the several forms of tissue are developed, their nutrition is kept up by the supply of their respective materials, which they derive from the blood. Each tissue draws

from the blood that which it requires; and as some portions of it undergo decomposition, others are newly formed. The germs of these newly-formed parts may be supplied in some instances by the blood, in others by the tissues themselves;—on this subject nothing certain can be at present stated. Where the new structure merely replaces that which has been removed by death and decay, it is probable that its germs are furnished by the part itself, drawing the materials of their development from the blood; just as the cell of the Red Snow or Yeast Plant, whilst itself dying, sets free the contained granules, which become the germs of new cells, obtaining their nourishment from the air and moisture around (VEGET. PHYS. §. 424). But where an entirely new structure is being formed, as in the process to be presently described (§. 393), it is probable that the blood both furnishes the germs and the materials for their development.

387. Though all the tissues derive the materials of their development from the blood which circulates in the vessels, yet there is considerable variety in the mode in which the supply is afforded; some tissues being supplied with blood much more copiously and directly than others, in consequence of the greater minuteness with which the capillaries are distributed through their substance. There are several, indeed, into which no blood-vessels enter, in their natural state; but which derive their nutriment by absorbing the *liquor sanguinis* that is brought into their neighbourhood. This is the case, for instance, with the epithelium and epidermis (§. 35, 39); the cells of which are developed at the expense of the fluid which they absorb, *through* the basement membrane on which they lie, from the vessels of the skin or mucous membrane beneath it. In like manner, even the thick layer of Cartilage which covers the ends of most of the long bones, is destitute of blood-vessels; and the small amount of nourishment it requires, is obtained by absorption from the vessels which surround it (§. 45). This tissue undergoes very little change from time to time; and its growth takes place chiefly by addition of new matter to its surface; consequently there is no necessity for any active circulation through its interior; and the transmission of nutritive fluid from

one cell to another (as in the cellular tissue of Plants) is sufficient for its wants. Even in Bone, the blood-vessels are not very minutely distributed; for although there is a close network of capillary vessels on the membrane lining the Haversian canals and the cells of the areolar structure (§. 47), yet none of these pass into the actual substance of the bone. The *Fibrous* tissues are, for the most part, but sparingly supplied with blood-vessels, as they are but little liable to decay or injury; but the delicate areolar tissue, which is continually undergoing change, receives a larger quantity of blood, being traversed by capillary vessels in every direction. It is by *its* means that blood-vessels are conveyed into the Adipose tissue; for the ultimate elements of that tissue, namely, the fat cells, are surrounded by capillary vessels, not entered by them. The same important purpose is answered by the areolar tissue that lies amongst the tubes which form the essential parts of the nervous and muscular tissues; for these tubes are not perforated by vessels, so that their contents must be nourished by fluid absorbed through their walls.

388. In no instance that we are acquainted with, in the higher animals at least, do the vessels directly pour the blood into any tissue, for the purpose of nourishing it. Unless there have been an actual wound, which has artificially opened the blood-vessels, no fluid can escape from them into the substance traversed by the capillaries, except by transuding the walls of the latter; and hence it would seem impossible, that any of the floating cells contained in the blood, can be deposited in the tissues and contribute to their development. The *liquor sanguinis* seems, therefore, to furnish all that is wanting for this purpose; and it readily permeates the walls of the capillaries, the basement membrane, and any other of the softer tissues, so as to arrive at the parts where it is to be applied. As it is withdrawn from the blood, it is continually being re-formed from the food; but if it be not supplied in sufficient quantity by the latter, the nutrition of the body cannot take place with its proper energy. The same result happens, if its fibrin is not properly elaborated. The tissues are imperfectly nourished; and the strength of the body, and the vigour of the mind, are consequently alike impaired.

389. This imperfect elaboration seems to be the essential condition of one of the most destructive diseases to which the human frame is liable,—that commonly known as Consumption. This is, however, but one out of several diseases, which may result from the same state of constitution. If the fibrin of the blood be imperfectly elaborated, it is less fit to undergo organisation; and consequently, instead of being converted into living tissue, part of it is deposited as an unorganisable mass, in the state known to the Medical man as *Tubercle*. Such deposits take place more frequently in the lungs than in any other part; and besides impeding the circulation and respiration, they produce irritation and inflammation, in the same manner as other substances imbedded in the tissues would do; so that the issue, although often postponed for a time, is almost invariably fatal, when once tubercular matter has been deposited in the lungs. Microscopic examination of tubercular matter shows that it consists of half-formed cells, fibres, &c., together with a granular substance, which seems to be little else than coagulated albumen. The only manner in which any curative means can be brought to bear upon this terrible scourge, is by attention to the constitutional state from which it results. This is sometimes hereditary; and is sometimes induced by insufficient nutrition, habitual exposure to cold and damp, long-continued mental depression, &c. The treatment must be directed to the invigoration of the system by good food, active exercise, pure air, warm clothing, and cheerful occupations; and by the due employment of these means, at a sufficiently early period, many valuable lives may be saved, which would have otherwise fallen a sacrifice to tubercular disease. For the earnestness with which he has directed general attention to this important topic, the British public are much indebted to the writings of Sir James Clark.

390. There is another remarkable class of diseases resulting from a disordered condition of the nutritive processes,—those, namely, of a *cancerous* nature. The peculiarity of the structure of the various forms of Cancer consists in this,—that they are composed of cells, sometimes of a globular form, sometimes elongated or spindle-shaped, having a power of rapid multiplica-

tion, and not capable of changing into any other kind of tissue. It is this rapidity of increase, combined with the tendency which the diseased growth has, to appear in one part of the body when removed from another, which gives to these diseases their peculiar character of *malignancy*. When a truly cancerous growth has once established itself in any part of the body, it may increase to any extent, obtaining its nourishment from the blood-vessels in its neighbourhood, and destroying the surrounding parts by its pressure, and by drawing off their supply of nourishment. When it has developed itself to a considerable degree, the Surgeon is disinclined to remove it; knowing that the disease will probably make its appearance in some other part of the body. It is probable that this extension of it is due to the conveyance of some of the germs of the Cancer-cells, by the blood, to distant parts of the body; in the same manner as the germs of the peculiar Mould, which constitutes the Muscardine of Silk-worms, are conveyed through *their* bodies (VEGET. PHYS. §. 54). Cancerous diseases may be propagated, like Muscardine, by inoculation from one animal to another; by which operation, some of the cell-germs are transplanted, as it were, into a new soil.

391. From the foregoing facts it is evident, that the operations of Nutrition are due, on the one hand, to the independent properties of the several tissues, which draw from the blood the materials of their continued growth and renewal; and, on the other, to the properties of the blood, which supplies them with these materials. The blood, left to itself, could form no tissue more complex than a mere fibrous network: and the various elaborate tissues of the body could not of themselves select and assimilate their nourishment, and are consequently dependent upon the blood for their supply. We may illustrate the relation between the three states,--that of aliment, blood, and organised tissue,—by comparing them with the three principal states which Cotton passes through, in the progress of its manufacture,—namely, the raw cotton, spun-yarn, and woven fabric. The spun-yarn could not of itself assume that particular arrangement which is given to it by the loom; and the loom could make nothing of the raw cotton, until it has been spun into yarn.

392. It is also evident, that the blood-vessels have no other purpose in the act of Nutrition, than to convey the circulating fluid into the neighbourhood of the part where it is to be employed: and the blood, or at least its organisable portion, the *liquor sanguinis*, must quit the vessels, before it can be employed in the development of new tissue. We might illustrate this by the distribution of water-pipes through a city; they might pass into every house, nay into every room; and yet the water must be drawn from the pipes, before it can be applied to any required purpose. The spaces untraversed by vessels have been shown to be larger in some tissues, and smaller in others; the distribution of the capillaries being more minute, in proportion as the nutritive actions of the part go on more energetically. Now in the embryo, even of the most complex and perfect animals, there is a period when no blood-vessels exist, the whole mass being made up of cells, every one of which lives *for* itself and *by* itself, absorbing nutriment from a common source, and not at all dependent upon its brethren. It is only when a diversity of structure begins to show itself,—one part undergoing transformation into bone, another into muscle, and so on,—and when some portions of the fabric are cut off from the direct supply of nourishment,—that vessels begin to show themselves. These are formed like the ducts of Plants, by the breaking down of the partitions between contiguous cells; and they bear a close resemblance, at an early period, to the vessels through which their nutritious sap or *latex* circulates through their tissues (VEGET. PHYS. §. 87).

393. When an entirely new structure is to be formed,—as for the closure of a wound, the union of a broken bone, or the repair of any other injury,—the process is of a kind very much resembling the first development of the entire fabric. The neighbouring vessels pour out their *liquor sanguinis*, which is known to the Surgeon under the name of *coagulable lymph;* this fills up the open space; and, when it coagulates, it forms a connecting medium between the separated parts. It would appear that, when coagulating upon a *living* surface, the fibrin contained in this fluid assumes a more perfect arrangement, than that which it usually presents when it coagulates out of the body; for the

lymph which is thus poured out soon begins to show a regular organisation; fibres and cells first appear in it; some of the cells speedily break down into vessels, which form connections with those in the nearest living part; the blood begins to circulate through the newly-forming tissue; and in time, such a change takes place in it, as converts its several portions into fabrics resembling those with which they are connected,—whether bone, nerve, fibrous membrane, mucous membrane, or skin; until the separation is complete and effectual. This is the mode of repair known to the Surgeon as *healing by the first intention.*—It often happens, however, that the destruction of tissue has been too great for its renewal in this manner; and a gradual process of growth from the surrounding solid parts, is then necessary. This may take place in two ways, according to the mode in which it is regulated. Under the most favourable circumstances, when the wound is completely excluded from the contact of air and from other sources of irritation, and when the constitution is not in an inflammatory state, there is a gradual and complete repair of the parts that have been lost, by the growth of the surrounding structures. This, which is termed by Dr. Macartney (who first described it) the *modelling process*, is nothing else than the simple natural process of development, analogous to that which takes place in the first production of the fabric, and in the regeneration of entire members that are lost among the lower animals (Chap. xv). But if inflammation be permitted to arise, the repair takes place by a process termed *granulation*, which consists in the sprouting forth of a rapidly-growing tissue (commonly known as *proud flesh*) that fills up the cavity; but this contracts after the skin has closed over it, and gives rise to an unsightly scar, which is completely avoided in the former method.

CHAPTER IX.

ON THE EVOLUTION OF LIGHT, HEAT, AND ELECTRICITY BY ANIMALS.

Animal Luminousness.

394. A large proportion of the lower classes of aquatic Animals possess, in a greater or less degree, the power of emitting light. The phosphorescence of the sea, which has been observed in every zone, but more remarkably between the tropics, is due to this cause. When a vessel ploughs the ocean during the night, the waves—especially those in her wake, or those which have beaten against her sides,—exhibit a diffused lustre, interspersed here and there by stars or ribands of more intense brilliancy. The uniform diffused light is chiefly emitted by innumerable minute animals, which abound in the waters of the surface; whilst the stars and ribands are due to larger animals, whose forms are thus brilliantly displayed. Both belong, for the most part, to the class Acalephæ, all the species of which appear to be more or less phosphorescent, those of tropical seas being the most so. This interesting phenomenon, when it occurs on our own coasts, is chiefly produced by incalculable multitudes of a small species, having a nearly globular form, and of a size about equal to that of the head of an ordinary pin. When these cover the water, and a boat is rowed among them, every stroke of the oars produces a flash of light; and the ripple of the water upon the shore is marked by a brilliant line. If a person walk over sands that the tide has left, his footsteps will seem as if they had been impressed by some glowing body. And if a small quantity of the water be taken up and rubbed between the hands, they will remain luminous for some time. The transparency of

the little animals, to which these beautiful appearances are due, might cause them to be overlooked, if they are not attentively sought; they much resemble grains of boiled sago in their aspect, but are much softer.

395. The light emitted by these animals appears to be due to the peculiar chemical nature of the *mucus* secreted from their bodies; for this, when removed from them, retains its properties for some time, and may communicate them to water or milk, rendering them luminous for some hours, particularly when they are warmed and agitated. It is probably from this source, that the diffused luminosity of the sea is partly derived. The secretion appears to be increased in amount, by anything that irritates or alarms the animals; and it is from this cause that the dashing of the waves against each other, the side of a ship, or the shore,—or the tread of the foot upon the sand,—or the compression of the animals between the fingers,—occasions a greater emission of light. But some of these causes may act, by bringing a fresh quantity of the phosphorescent secretion into contact with air, which seems necessary to maintain the kind of slow combustion on which the light depends.

396. But the Acalephæ are by no means the only luminous animals which tenant the deep. Many of the POLYPIFERA appear to have this property in an inferior degree, and also some of the ECHINODERMATA. Of the lowest class of Mollusca, the TUNICATA, a very large proportion are luminous, especially those which float freely through the ocean, and which abound in the Mediterranean and tropical seas; the brilliancy of some of these can scarcely be surpassed. Among some of the shell-bearing Molluscs, the phenomenon has also been observed; and also in the marine Annelida. Other marine animals of higher classes are possessed of similar properties; thus, many CRUSTACEA, especially the minuter species, are known to emit light in brilliant jets; and the same may be said of a few FISHES: but it is probable that the luminosity attributed to many of the latter, is due to the disturbance they make in the surrounding water, which excites its phosphorescence in the manner just explained. In all these, the general phenomena are analogous,—the luminous

matter appearing to be a secretion from the surface of the animals, and to undergo a sort of slow combustion by combination with oxygen. Wherever it is presented by these animals, it is always most brilliant upon the surfaces concerned in respiration. The light continues for some days after death; but ceases at the commencement of putrefaction.

397. In the class of INSECTS, there are several species which have considerable luminous power; and in these the emission of light is for the most part confined to a small part of the surface of the body, from which it issues with great brilliancy. The luminous Insects are most numerous among the Beetle tribe; and are nearly restricted to two families, the *Elateridæ*, and the *Lampyridæ*. The former contains about 30 luminous species, which are known as *fire-flies*; these are all natives of the warmer parts of the New World. Their light proceeds from two minute but brilliant points, which are situated one on each side the front of the thorax; and from another beneath the hinder part of the thorax, which is only seen during flight. The light proceeding from these points is sufficiently intense to allow small print to be read in the profoundest darkness, if the insect be held in the fingers and be moved along the lines; and the natives of the countries where they are found (particularly in St. Domingo, where they are abundant) use them instead of candles in their houses, and tie them to their feet and heads, when travelling at night, to give light to their path through the forest. In all the luminous species of this family, the two sexes are equally phosphorescent.*

398. The family *Lampyridæ* contains about 200 species known to be luminous; the greater part of these are natives of

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* This insect has been happily introduced by the poet Southey in his "*Madoc*," as furnishing the lamp by which the British hero was rescued from the hands of the Mexican priests:—

"She beckoned and descended, and drew out
From underneath her vest a cage, or net
It rather might be called, so fine the twigs
Which knit it, where, confined, two Fire-flies gave
Their lustre. By that light did Madoc first
Behold the features of his lovely guide."

America, whilst others are widely diffused through the Old World. In most of these, the light is most strongly displayed by the female, which is usually destitute of wings, so that it might be mistaken for a larva. The species of our own country is known as the *Glow-worm*. "Who that has ever enjoyed the luxury of a summer evening's walk in the country, in the southern parts of our island, but has viewed with admiration these stars of the earth and diamonds of the night? And if, living like me in a district where it is rarely to be met with, the first time you saw this insect chanced to be, as it was in my case, one of those delightful evenings which an English summer rarely yields, when not a breeze disturbs the balmy air, and 'every sense is joy,' and hundreds of these radiant worms, studding their mossy couch with mild effulgence, were presented to your wondering eye in the course of a quarter of a mile,—you could not help associating with the name of glow-worm the most pleasing recollections. No wonder that an insect which chiefly exhibits itself on occasions so interesting, and whose economy is so remarkable, should have afforded exquisite images and illustrations to those poets who have cultivated Natural History."*

399. The light of the glow-worm issues from the under surface of the three last abdominal rings. The luminous matter, which consists of little granules, is contained in minute sacs, covered with a transparent horny lid; and this exhibits a number of flattened surfaces, so contrived as to diffuse the light in the most advantageous manner. The sacs are mostly composed of a close network of finely divided air-tubes (§. 320); which ramify through every part of the granular substance; and it appears that the access of air through these is a necessary condition of the phosphorescence. For if the aperture of the large trachea which supplies the luminous sac be closed, the light ceases; but if the sac be lifted from its place, without in-

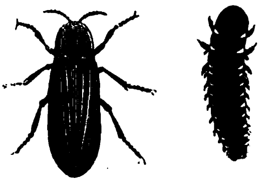

FIG 162.—MALE AND FEMALE GLOW-WORM.

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* Kirby and Spence's Entomology, vol. II. p. 331.

juring the trachea, the light is not interrupted. All the luminous insects appear to have the power of extinguishing their lights; and this they probably do when alarmed by approaching danger. This circumstance is beautifully alluded to, in the following elegant description, by the poet already quoted, of the first effect of the brilliant nocturnal spectacle, presented by these insects in the countries where they abound, upon the British visitors of the New World.

> "———— Sorrowing we beheld
> The night come on; but soon did night display
> More wonders than it veiled; innumerous tribes
> From the wood-cover swarm'd, and darkness made
> Their beauties visible: one while they stream'd
> A bright blue radiance upon flowers that closed
> Their gorgeous colours from the eye of day;
> Now motionless and dark, eluded search,
> Self-shrouded; and anon, starring the sky,
> Rose like a shower of fire."

The sudden extinction of the light is probably due to the animal's power of voluntarily or instinctively closing the aperture of the trachea.

400. There are a few other Insects not included in these families, which are reputed to possess luminous powers; and of these the most remarkable are the *Fulgoræ*, or Lantern-flies, of which one species inhabits Guiana, whilst another is a native of China. These are insects of very remarkable form, having an extraordinary projection upon the head; and this is the part said to be luminous. The authority for the assertion, however, is doubtful; and many Entomologists, who have captured the insect, have denied the phosphorescent power imputed to it. But it is not impossible that the female only may possess it; and that it may only be manifested at one part of the year. One of the common English species of Centipede,

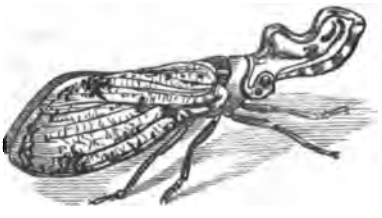

FIG. 163.—FULGORA LANTERNARIA.

which is found in dark damp places, beneath stones, &c., is slightly luminous; and the common Earth-worm is also said to be so at the breeding season.

401. Of the particular objects of this provision in the Animal economy, little is known, and much has been conjectured. It is not requisite to suppose that its purposes are always the same; the circumstances of the different tribes which possess it being so different. The usual idea of its use in Insects,—that it enables the sexes of the nocturnal species to seek each other for the perpetuation of the race,—is probably the correct one. The light is more brilliant at the season of the exercise of the reproductive functions than at any other, and is then exhibited by animals which do not manifest it at any other period. Moreover, it is well known that the male Glow-worm,—which ranges the air, whilst the female, being destitute of wings, is confined to the earth,—is attracted by any luminous object; as are also the Fire-flies, which may be most easily captured by carrying a torch or lantern into the open air: so that the poetical language, in which this phosphorescence is described as "the lamp of love —the pharos—the telegraph of the night, which marks, by its scintillations, in the silence of the night, the spot appointed for the lovers' rendezvous," would not seem so incorrect as the ideas of poets on subjects of Natural History too frequently are. It may be objected, on the other hand, that there are many Moths and Beetles, which have a similar tendency to fly towards the light, but which themselves possess no shining lamps. Some of these, however, are faintly luminous; and it would not seem improbable that the Insects which are attracted by flame, and thus show that they are seeking for objects which emit light, may be able to perceive feebler degrees of it—undistinguishable by our eyes—that may be possessed by the beings of which they are in search.

402. Regarding the uses of the luminosity of the lower marine tribes, it is more difficult to form a definite idea; since many of them are fixed to one spot during the whole of life, and in many others the sexes do not require to seek each other. It may serve for the illumination (however faintly) of those dark

and rayless depths of the ocean, which are known to be tenanted by Fishes and other animals, although they receive no appreciable portion of solar light; and it may be sufficient to direct these to their prey. It has also been suggested, that the property may be conferred upon them (like the stinging powers possessed by some) as a means of self-defence; their bodies not being protected by a dense external covering, nor possessed of the means of escape from danger by rapid motion. Many of them have the power of throwing out momentary vivid flashes of light, which would not seem producible by the secretion already described; and these may have the effect of scaring away the animals that would otherwise make them a prey.

It not unfrequently happens, that an evolution of light takes place from the bodies of animals soon after their death, but before their decomposition has advanced far. This has been most frequently observed to proceed from the bodies of Fishes, Mollusca, and other marine tribes; but it has been seen also to be evolved from the surface of land animals, and even from the Human body. Indeed, some well-authenticated cases have been recently put on record,* in which a considerable amount of light was given off from the faces of living individuals, who were near their end. All animal bodies contain a considerable quantity of phosphorus (§. 167); and it is by no means impossible that some peculiar compound of this substance may be formed, during the early stages of decomposition, and even before death; and may, by its slow combustion, give rise to the luminous appearance. It appears that the whole substance of the body of the Fire-flies is phosphorescent; for, according to an early historian of the West Indies, "many wanton wilde fellowes" rub their faces with the flesh of a killed Fire-fly, "with purpose to meet their neighbours with a flaminge countenance."

Animal Heat.

403. One of the conditions necessary for the performance of vital action, is a certain amount of warmth; and we have seen

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* See Sir H. Marsh, on the Evolution of Light from the Living Human Subject.

that the animals which alone are capable of retaining their activity in the coldest extremes of temperature, are those which have the power of generating heat within themselves, and thus of keeping up the temperature of their bodies to a high standard. Those which do not possess a power of this kind are either rendered completely inactive, even by a comparatively moderate cold, or are altogether destroyed by it. Those which ordinarily do possess this power, are destroyed even more rapidly by cold, if from any cause the production of heat within their bodies be interrupted; for they are the animals, whose vital actions are the most varied and energetic, and in which an interruption to any one of them most speedily brings the rest to a stand. The inquiry into the amount of heat generated by different animals, and the sources of its production, is one, therefore, of great practical importance.

404. Our knowledge of the heat evolved by the lower Invertebrated animals is very limited; but it is probable that in most of them the temperature of the body follows that of the element they inhabit, keeping a little above it for a time, when it is much lowered. Thus, when water containing *Animalcules* is frozen, they are not at once destroyed; but each lives for a time in a small uncongealed space, where the fluid seems to be kept from freezing by the heat liberated from its body. The temperature of Earth-worms, Leeches, Snails, and Slugs, ascertained by introducing a thermometer into the midst of a heap of them, is usually about a degree or two above that of the atmosphere; and they also have the power of resisting for a time the influence of a degree of cold, that would otherwise immediately freeze their bodies.

405. In the cold-blooded Vertebrata, also, the heat of the body is almost entirely dependent upon that of the surrounding element. Thus most FISHES are incapable of maintaining a temperature more than two or three degrees higher than that of the water in which they live; and the warmth of their bodies consequently rises and falls with that of the sea, river, or lake they may inhabit. There are, however, a few marine fishes which have the power of maintaining a temperature 10 or 12

degrees higher than that of the sea; and these are peculiar for the activity of their circulation, and the deep colour of their blood, which possesses red particles (§. 229) enough to give to the muscles a dark red colour like that of meat. The *Thunny*, a fish which abounds in the Mediterranean, where there are extensive fisheries for it, is one of this group.—It is to be remembered that the animals of this class are less liable to suffer from seasonal alternations of temperature, than those which inhabit the air. In climates subject to the greatest atmospheric changes, the heat of the sea is comparatively uniform throughout the year, and that of deep lakes and rivers is but little altered. Many have the power of migrating from situations where they might otherwise have suffered from cold, into deep waters; and those species which are confined to shallow lakes and ponds, and which are thus liable to be frozen during the winter, are frequently endowed with sufficient tenacity of life, to enable them to recover after a process which is fatal to animals much lower in the scale. Fishes are occasionally found imbedded in the ice of the Arctic seas; and some of these have been known to revive when thawed.

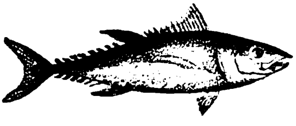
FIG. 164.—THUNNY.

406. In REPTILES, the power of maintaining an uniform temperature is somewhat greater; being especially shown when the external temperature is reduced very low. Thus when the air is between 60 and 70 degrees, the body of a Reptile will be nearly of the same heat; but when the air is between 40 and 50 degrees, it may be several degrees higher. Frogs and other aquatic Reptiles have a remarkable power of sustaining a temperature above that of freezing, when the water around is not only congealed, but is cooled down far below the freezing-point. Thus in ice of 21 degrees, the body of an edible frog has been found to be 37½ degrees; and even in ice of 9 degrees, the animal has maintained a temperature of 33 degrees. In these cases, as in Animalcules, the water in immediate contact with the body remains fluid, so long as the animal can generate heat; but at

last it is congealed, and the body is also completely frozen. But it is certain that Frogs, like Fishes, may be brought to life again, after the fluids of their bodies have been so completely congealed, that the limbs become quite brittle; it is not known, however, whether this may happen with other Reptiles. It would appear that among Reptiles, as among Fishes, some of the more active species have the power of maintaining their bodies at a temperature considerably higher than that of the atmosphere; thus in some of the more agile of the Lizard tribes, the high temperature of 86 degrees has been noticed, when the external air was but 71 degrees.

407. The only classes of animals in which a constantly-elevated temperature is kept up, are BIRDS and MAMMALIA. The bodily heat of the former varies from 100° to 112°; the first being that of the Gull, the last that of the Swallow. In general we find that the temperature is the highest in species of rapid and powerful flight; and least in those which inhabit the earth. Birds that are much in the water have a special provision for retaining within their bodies the heat which would otherwise be too rapidly conducted away; their bodies being clothed with a thick and soft down, which is rendered impenetrable to fluid by an oily secretion applied with the bill. The temperature of the MAMMALIA seems to range from 96° to 104°; but more accurate and extensive observations, especially on the temperature of the same species under different circumstances, are much wanting. From the observations of Dr. J. Davy upon the temperature of Man, it appears that the *mean* or *average* heat of his body is about 100°; he has observed it as low as 96½°, when the temperature of the air was 60°; and as high as 102°, when the air was at 82°. Thus we see that a variation of 5½ degrees was witnessed when the range of the temperature of the air was only from 60° to 82°; and it is probable that observations made in cold climates will show, that the temperature of the body may be still further lowered, when that of the air around is much depressed. But it seems that, in Man, as in other animals, the lower the temperature of the air around, the greater is his power of generating heat within his body, to keep up the necessary

standard; and no observations yet made, indicate that the temperature of the body ever falls below 95° in health. In Asthma and Asiatic Cholera, however, it has been found 20° below its usual standard; and in Scarlet-fever and Tetanus (locked-jaw) it has been known to rise to 106° and 110¾°.

408. The young of warm-blooded animals have usually less power of maintaining an independent heat than adults. The embryo, whether in the egg, or within the body of the parent, is dependent upon external sources for the heat necessary to its full development. The contents of the egg, when lying under the body of its parent, are so situated, that the germ-spot (Chap. xv.) is brought into the nearest neighbourhood of the source of warmth. It is not usually until some weeks after the hatching of Birds, or the birth of Mammalia, that the young animals have the power of maintaining an independent temperature. Thus young Sparrows, taken from the nest a week after they were hatched, were found to have a temperature of from 95° to 97°; but this fell in one hour to 66½°, the temperature of the atmosphere being at the same time 62½°; and the rapid cooling was proved not to be due to the want of feathers alone. There are some birds, however, which can run about and pick up their food the moment they are hatched; these come into the world in a more advanced condition than the rest, and can maintain their temperature with little or no assistance. We find the same to be the case among Mammalia. There are some species (such as the Guinea-pig) whose young are able from birth to walk and run, and to take the same food with the mother; and these have from the first the power of maintaining a steady temperature when the air around is not very cold. But in general, the young of Mammalia are much less advanced at the time of birth, being not unfrequently born blind as well as helpless; and they require considerable assistance, in keeping up their heat, from the parent or nurse. Thus the temperature of new-born puppies, removed from the mother, will rapidly sink to between 2° and 3° above that of the air.

409. These facts are of extreme practical importance, in regard to the treatment of the Human infant. Though not

destitute of sight, at its entrance into the world, like the young of the Cat, Dog, or Rabbit, it is equally helpless, and dependent upon its parent not only for support but for warmth. And as the Human body is longer in arriving at its full development than is any other, so is it necessary that this assistance should be longer afforded. This assistance is the more necessary in the case of infants born prematurely; and it should be kept up during the years of childhood, gradually diminishing with age. It is too frequently neglected, by those who are well able to afford it, under the erroneous idea of hardening the constitution; and the want of it, consequent upon poverty, is one of the most fertile sources of the great mortality among children of the poorer classes. This is easily proved by the proportional number of deaths which take place in different parts of the year, at different ages. During the first month of infant life, the winter mortality is nearly double that of the summer; though there is very little difference between the two seasons in the mortality of adults. But in old age the difference again manifests itself to the same amount as in infants; for old persons are almost equally deficient in the power of maintaining heat; they complain that their "blood is chill," and suffer greatly from exposure to cold.

410. The class of Insects presents us with some very extraordinary and interesting phenomena. In the *larva* and *pupa* states, the temperature of the body is never more than from ½° to 4° above that of the surrounding medium; but in many tribes, the temperature of the perfect Insect rises so high, when it is in a state of activity, that it might be at such times called a warm-blooded animal; though in the states of abstinence, sleep, and inactivity, its temperature falls again nearly to that of the atmosphere. A single Humble-bee, inclosed in a phial of the capacity of 3 cubic inches, had its temperature speedily raised by violent excitement, from that of rest (2° or 3° above that of the atmosphere) to 9° above that of the external air; and communicated to the air in the phial as much as 4° of heat within five minutes. In another similar experiment, the temperature of the air in the phial was raised nearly 6° in eight minutes. It is among the active Butterflies, and the Hymenopterous

insects (Bee and Wasp tribe), which pass nearly the whole of their active condition on the wing, that we find the highest temperature; and next to them are the most active of the Beetle tribe. Those of the latter which seldom leave the ground, have little power of producing heat.

411. The greatest manifestation of this power is shown among Insects which live in societies; most of which belong to the order Hymenoptera. It has been seen that the body of a Humble-bee, in a state of activity, has a temperature of about 9° above that of the atmosphere; but its nest has been found to have an ordinary temperature of from 14° to 16° above the air, and from 17° to 19° above that of the chalk bank in which it was formed. But the production of heat is increased to a most extraordinary degree when the *pupæ* are about to come forth from their cells as perfect Bees, and require a higher temperature for their complete development. This is furnished by a set of Bees termed *Nurse-bees*, which are seen crowding upon the cells and clinging to them, for the purpose of communicating to them their warmth; at the same time being evidently very much excited, and respiring rapidly, even at the rate of 130 or 140 inspirations per minute. In one instance, the thermometer introduced amongst seven nursing-bees stood at 92½°; whilst the temperature of the external air was but 70°. In Hive-bees, whose societies are large, this process occasions a still more remarkable elevation of temperature; for a thermometer introduced into a hive during May has been seen to rise to 96° or 98°, when the range of atmospheric temperature was between 56° and 58°. In September, when the bees are becoming stationary, the temperature of the hive is but a few degrees above that of the air. It was formerly supposed that Bees do not become torpid during the winter; but this is now known to be a mistake. Bees, like other Insects, pass the winter in a state of hybernation; but their torpidity is never so profound, as to prevent their being aroused by moderate excitement. The temperature of a hive is usually from 5° to 20° above that of the atmosphere; being kept at or above the freezing-point, when the air is far below it. Under such circumstances, their power of

generating heat is most remarkable. In one instance, the temperature of a hive, of which the inmates were aroused by tapping on its outside, was raised to 102°; whilst a thermometer in a similar hive that had not been disturbed, was only 48½°; and the temperature of the air was 34½°.

412. The cause of the evolution of heat in the Animal body, may now be referred with tolerable certainty, to the union, by a process resembling ordinary combustion, of the carbon and hydrogen of the system, with the oxygen taken in from the air, in the process of Respiration. It has been elsewhere shown that, even in Plants, this union, when it takes place with sufficient rapidity, is accompanied by the disengagement of a considerable amount of heat (VEGET. PHYS., §. 411); and in all those Animals which can maintain an elevated temperature, we find a provision for this union, both in regard to the constant supply of carbon and hydrogen from the body, and to the introduction of oxygen from the air. The supply of carbon and hydrogen may be derived (as already shown, §. 157), either *directly* from the food, a large proportion of which is thus consumed in many animals, without ever forming part of the tissues of the body; or it may be the result of the waste of the tissues, especially of the muscular, consequent upon their active employment (§. 160). Or, again, it may be derived from the store laid up in the system in the form of *fat;* which seems destined to afford the requisite supply, when other sources fail. Thus in diseases which prevent the reception of food, the fat in the body rapidly diminishes; being burnt off, as it were, to keep up the temperature of the system. This is the case, too, during *hybernation;* the animals which undergo this change usually accumulating a considerable amount of fat in the autumn, and being observed to come forth from their winter quarters, with the return of spring, in a very lean condition.—In animals which do not require the maintenance of a high temperature, but which nevertheless eat with great voracity, such as the Mollusca and Crustacea, we find the superfluous portion of the carbon and hydrogen of the body carried off by means of the liver; in the secretion from which, these elements form a very large part (§. 364).

413. On the other hand, we find in all Animals, that are endowed with the power of developing much heat, a provision for introducing a large quantity of oxygen into the body, to unite with these elements, and to carry them off in the form of carbonic acid gas and watery vapour. We have seen that, in Insects, the air is itself conveyed, by means of air-tubes, into every part of the body (§. 320); and that, in the warm-blooded Vertebrata, its oxygen is equally distributed through the system, by means of the blood, and chiefly by its red corpuscles (§. 234). We find the number of these corpuscles to correspond exactly with the amount of heat maintained by each class of animals: thus in Birds, the blood is redder than in the Mammalia; in the Mammalia it is far redder than in Reptiles and Fishes; and in those of the latter class which can maintain a higher temperature than the rest, it is redder than in the white-fleshed species of less active habits (§. 405). The consumption of oxygen, moreover, and the production of carbonic acid, are found to take place in every animal, exactly in proportion to the amount of heat liberated at the time. Thus in warm-blooded animals, the respiratory function is much more active than in the cold-blooded; but when the former are reduced to the state of cold-blooded animals, as occurs in hybernation (§. 309), their respiration is proportionally low; and the diseases which cause a lowering of the temperature, are precisely those in which there is a diminished consumption of oxygen. On the other hand, whenever the temperature of an animal is quickly raised by any extraordinary stimulus, above that which it was previously maintaining, it is always by means of increased activity of the respiratory movements, and augmented consumption of oxygen. Thus during the incubation of Bees (§. 411), the insect, by accelerating its respiration, causes the evolution of heat, and the consumption of oxygen, to take place at least *twenty* times as rapidly as when in a state of repose. The same takes place when a hybernating animal is roused; and it is remarkable that even extreme cold will effect this for a time; but if the animal be exposed for too long a period to a very low temperature, it will not be able to resist its influence, and will perish.

414. The influence of respiration in maintaining the heat of the body, is well shown by the fact, that, if the brain be removed, but the top of the spinal cord (which is the centre of the actions of respiration, §. 450) be left, so that the movements of breathing continue, the temperature of the body is kept up with little diminution; and even if this be removed, and the respiration be artificially kept up, by blowing air into the lungs and pressing it out again, the body will cool much more slowly than it would otherwise have done. That this substitute will not *fully* answer the purpose, is easily understood, when we contrast the natural with the artificial respiration. In the natural, the air-cells are first dilated, and the air rushes into them from the air-tubes; in the artificial, the air is sent first into the air-tubes, and cannot properly distend the air-cells so as to act upon the blood, unless an injurious amount of force be employed.

415. It may be concluded, from this and other experiments, that the Nervous System has no *direct* influence in maintaining the temperature of the body, as some physiologists have supposed. It is true that the temperature of a paralytic limb is usually a degree or two lower than that of the sound one, and that it is more affected by changes of external temperature; but this is readily accounted for by the fact, that its inactivity prevents or retards those changes in its substance, which contribute to the maintenance of its heat. And the fact that heat is developed in Plants, which have no nervous system, to as high a degree as in Animals which possess it, when other circumstances are the same, should be enough to show that we are to look for its source in the various changes which the elements of the body are undergoing. Of these changes, the union of its carbon and hydrogen with oxygen taken in from without, are unquestionably the most constant and important; and we know that this union would produce the same effect *out* of the living body as in it; but there may be others, which are also concerned in the production of heat, though in a less degree.

Animal Electricity.

416. Almost all chemical changes are attended with some alteration in the electric state of the bodies concerned; and when

we consider the number and variety of these changes in the living animal body, it is not surprising that disturbances of its *electric equilibrium* (see Treatise on ELECTRICITY) should be continually occurring. But these, when slight, can only be detected by very refined means of observation; and it is only when they become considerable that they attract notice. Some individuals exhibit electric phenomena much more frequently and powerfully than others. There are persons, for instance, who scarcely ever pull off articles of dress which have been worn next the skin, without sparks and a crackling noise being produced, especially in dry weather. This is partly due, however, to the friction of these materials on the surface and with each other; for it is greatly influenced by their nature. Thus, if a black and white silk stocking be worn, one over the other, on the same leg, the manifestation of electricity when they are drawn off, especially after a dry frosty day, is most decided; but this would also be the case if they were simply rubbed together, without any connection with the body.

417. The most remarkable case of the production of electricity in the Human being, at present on record, is one lately related on excellent authority in America. The subject of it, a lady, was for many months in an electric state so different from that of surrounding bodies, that, whenever she was but slightly insulated by a carpet or other feebly-conducting medium, sparks passed between her person and any object which she approached. From the pain which accompanied the passage of the sparks, her condition was a source of much discomfort to her; when most favourably circumstanced, four sparks per minute would pass from her finger to the brass ball of a stove, at a distance of 1½ inch. The circumstances which appeared most favourable to the production of electricity were an atmosphere of about 80°, tranquillity of mind, and social enjoyment; while a low temperature and depressing emotions diminished it in a corresponding degree. The phenomenon was first noticed during the occurrence of a vivid Aurora Borealis; and though its first appearance was sudden, its departure was gradual. Various experiments were made, with the view of ascertaining if the electricity was pro-

duced by the friction of articles of dress; but no change in these seemed to modify its intensity.

418. In most animals with a soft fur, sparks may be produced by rubbing it, especially in dry weather; this is familiar to most persons in the case of the domestic Cat. But the electricity thus produced seems occasionally to accumulate in the animal, as in the Leyden Jar, so as to produce a shock. If a cat be taken into the lap, in dry weather, and the left hand be applied to the breast, whilst with the right the back be stroked, at first only a few sparks are obtained from the hair; but after continuing to stroke for some time, a smart shock is received, which is often felt above the wrists of both the arms. The animal evidently itself experiences the shock, for it runs off with terror, and will seldom submit itself to another experiment.

419. But there are certain animals, which are capable of producing and accumulating electricity in large quantities, by means of organs specially adapted for the purpose; and of discharging it at will, with considerable violence. It is remarkable that all these belong to the class of Fishes;* and that they should differ alike in their general conformation, and in their geographical distribution. Thus, the two species of *Torpedo*, belonging to the Ray tribe, are found on most of the coasts of the Atlantic and Mediterranean; and sometimes so abundantly, as to be a staple article of food. The *Gymnotus*, or Electric Eel, is confined to the rivers of South America. The *Silurus* (more correctly, the *Malapterurus*), which approaches more nearly to the Salmon tribe, occurs in the Niger, the Senegal, and the Nile; and there are two other less known Fishes, said to possess electric properties, which inhabit the Indian seas.

420. Of all these, the *Gymnotus* is the one which possesses the electric power in the most extraordinary degree. It is an eel-like fish, having nothing remarkable in its external appearance; its usual length is from six to eight feet; but it is said occasionally to attain the length of twenty feet. This fish will attack and paralyse horses, as well as kill small animals; and the dis-

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* Certain Insects and Mollusca have been said to possess electrical properties; but no special electric organ has been discovered in them.

charges of the larger individuals sometimes prove sufficient to deprive even men, of sense and motion. This power is employed by the fish to defend itself against its enemies; and even, it is said, to destroy its prey (which consists of other fishes) at some distance; the shock being conveyed by water, as a lightning-conductor conveys to the earth the effects of the electric discharge of the clouds. The first shocks are usually feeble; but as the animal becomes more irritated, their power increases. After a considerable number of powerful discharges, the energy is exhausted, and is not recovered for some time; and this circumstance is taken advantage of in South America, both to obtain the fishes (which afford excellent food), and to make the rivers they infest passable to travellers. A number of wild horses are collected in the neighbourhood and driven into the water; the Gymnoti attack these, and speedily stun them, or even destroy their lives by repeated shocks; but their own powers of defence and injury are exhausted in the same degree, and they then become an easy prey to their captors.

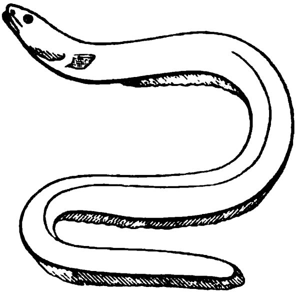

FIG. 165.—GYMNOTUS.

421. The shock of the *Torpedo* is less powerful; but it is sufficient to benumb the hand that touches it. From its proximity to European shores, this fish has been made the subject of observation and experiment, more completely than the other; and some curious results have been attained. It seems essential to the proper reception of the shock, that two parts of the body should be touched at the same time; and that these two should be in different electrical states. The most energetic discharge is procured from the Torpedo, by touching its back and belly simultaneously; the electricity of the back being positive, and

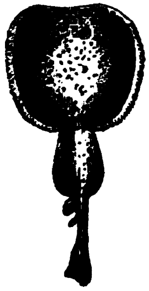

FIG. 166.—COMMON TORPEDO.

that of the belly negative. When two parts of the same surface, at an equal distance from the electric organ, are touched, no effect is produced; but if one be further from it than the other, a discharge occurs. It has been found that, however much a Torpedo is irritated through a single point, no discharge takes place; but the fish makes an effort to bring the border of the other surface in contact with the offending body, through which a shock is then sent. This, indeed, is probably the usual manner in which its discharge is effected. If the fish be placed between two plates of metal, the edges of which are in contact, no shock is perceived by the hands placed upon them, since the metal is a better conductor than the human body; but, if the plates be separated, and, while they are still in contact with the opposite sides of the body, the hands be applied to them, the discharge is at once rendered perceptible, and may be passed through a line formed by the moistened hands of two or more persons. In the same manner, also, a visible spark may be produced; but this is less easily obtained from the Torpedo than from the Gymnotus.

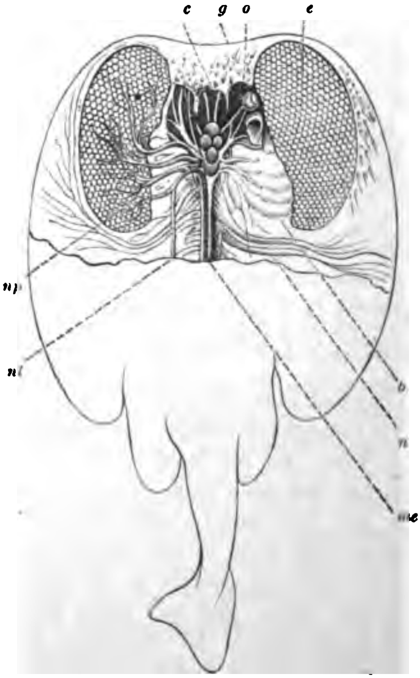

FIG. 167.—ELECTRIC APPARATUS OF TORPEDO.

c, brain; *me*, spinal cord; *o*, eye and optic nerve; *e*, electric organs; *np*, pneumogastric nerve, supplying electric organs; *nl*, lateral nerve; *n*, spinal nerves.

422. The electric organs of the Torpedo are of flattened shape, and occupy the front and sides of the body,

forming two large masses, which extend backwards and outwards from each side of the head. They are composed of two layers of membrane, the space between which is divided by vertical partitions, into hexagonal cells like those of a honeycomb (*e*, Fig. 167), the ends of which are directed towards the two surfaces of the body. These cells,—which are filled with a whitish soft pulp, somewhat resembling the substance of the brain, but containing more water,—are again subdivided horizontally by little membranous partitions; and all these partitions are profusely supplied with vessels and nerves. The electrical organs of the Gymnotus are essentially the same in structure, but differ in shape in accordance with the conformation of the animal; they occupy one-third of its whole bulk, and run nearly along its entire length, being arranged in two distinct pairs, one much larger than the other. In the Malapterurus, there is not any electrical organ so definite as those just described; but the thick layer of dense areolar tissue, which completely surrounds the body, appears to be subservient to this function,—being composed of tendinous fibres interwoven together, and containing a gelatinous substance in its interstices, so as to bear a close analogy with the special organs of the Torpedo and Gymnotus.

FIG. 168.—ELECTRIC MALAPTERURUS.

423. In all these instances, the electrical organs are supplied with nerves of very great size, larger than any others in the same animals, and larger than any nerves in other animals of like bulk. These nerves arise from the top of the spinal cord, and seem analogous to the pneumogastric nerve (§. 458) of other animals. The influence of these nerves is essential to the action of the electric organs. If all the trunks on one side be cut, the power of the corresponding organ will be destroyed, but that of

the other may remain uninjured. If the nerves be partially destroyed on either or both sides, the power is retained by the portions of the organs which are still connected with the brain by the trunks that remain. Even slices of the organ entirely separated from the body, except by a nervous fibre, may exhibit electrical properties. Discharges may be produced, by irritating the part of the nervous centres from which the trunks proceed (so long, at least, as *they* are entire), or by irritating the trunks themselves. In all these respects, there is a strong analogy between the action of the nerves on the electric organs, and on the muscles (Chap. XII.); and there is the same objection to the idea that the influence of the nerves is itself electrical; for if the nerves be *tied*, their power of exciting the electric organs is destroyed as completely as if they were cut. As to the mode in which the nerves cause these organs to generate electricity, we know nothing whatever; but we know nothing more of the manner in which they excite muscular contraction; and we must be satisfied for the present to remain ignorant of it.

424. As to the uses of the electrical organs to the animals which possess them, no definite information can be given. It is doubtful to what extent they are employed in obtaining food; since it is known that the Gymnotus eats very few of the fishes which it kills by its discharge; and that Torpedos kept in captivity do not seem disposed to exercise their powers on small fishes placed in the water with them. The chief use of the electrical power appears to be, to serve as a means of defence, to the Fishes which possess it, against their enemies.

CHAPTER X.

FUNCTIONS OF THE NERVOUS SYSTEM.

425. The preceding Chapters have been devoted to the consideration of the Functions of Organic Life,—those changes, namely, in the Animal body, which are concerned in the maintenance of its own fabric; and which, although performed in a different *mode*, and having different *objects* to fulfil, are essentially the same in *character* with those which take place in Plants. The first and most striking difference of mode results, as we have seen, from the nature of the food of Animals; which requires that they should possess a cavity for its reception, and a chemical and mechanical apparatus for its digestion (or reduction to the fluid form), in order that it may be prepared for absorption into the vessels. In regard to the absorption of the aliment, and its circulation through the system, there is but little essential difference between Plants and the lower Animals; but in the higher tribes of the latter, we find that a muscular organ, having the action of a forcing-pump, is appended to the system of tubes in which the fluid circulates, in order to drive it through them with the requisite certainty and energy. The respiration of Animals, again, is essentially the same with that of Plants; the chief difference being that, in order to secure the active performance of this important function, the higher Animals are provided with a complex apparatus of nerves and muscles, by which the air or water in contact with the aerating surface is continually renewed. And in regard to the functions of secretion and excretion, we have seen that, though there is a wide difference in the *form* of the organs by which they are executed, they are the same in essential structure; and that the difference in their mode of operation consists chiefly in this, that their products in the

Animal are destined to be carried out of the body, instead of being retained within it, as in Plants.

426. In regard to the immediate object of these functions, also, there is but little essential difference; for in both instances it is the conversion of alimentary materials into living organised tissue. But the ultimate purpose of this tissue is far from being the same in the two kingdoms. Nearly all the nourishment taken in by Plants is applied to the extension of their own fabric; and hence there is scarcely any limit to the size they may attain. There is very little waste or decay of structure in them, the parts once formed (with the exception of the leaves and flowers) continuing to exist for an indefinite time; this is a consequence of the simply *physical* nature of the functions of the woody structure, which has for its chief object to give support to the softer parts, and to serve as the channel for the movement of the fluid that passes towards and from them.—The case is very different in regard to Animals. With the exception of those inert tribes which may be compared with Plants in their mode of life, we find that the whole structure is formed for motion; and that every act of motion involves a waste or decay of the fabric which executes it. An energetic performance of the nutritive actions is required, therefore, in the more active Animals, simply to make good the loss which thus takes place; we find, too, that their size is restrained within certain limits; so that, instead of the nourishment taken into the body being applied, as in Plants, to the formation of new parts, it is employed for the most part in the simple repair of the old. Thus we may say that, whilst the object of Vegetable Life is to build up a vast fabric of organised structure, the purpose of the Organic Life of Animals is to construct, and to maintain in a state fit for use, the mechanism which is to serve as the instrument of their Animal Functions,—enabling them to receive sensations, and to execute spontaneous movements, in accordance with their emotions, instincts, or will.

427. This mechanism consists of two kinds of structure,—the Nervous and Muscular; which have entirely different offices to perform. The *Nervous* system is that which is the actual

instrument of the *mind*. Through its means, the individual becomes conscious of what is passing around him ; its operations are connected, in a manner we are totally unable to explain, with all his thoughts, feelings, desires, reasonings, and determinations; and it communicates the influence of these to his muscles, exciting them to the operations which he desires or determines to execute. But *of itself* it cannot produce any movement, or give rise to any action ; any more than the expansive force of Steam could set a mill in motion, without the machinery of the Steam-Engine for it to act upon. The *Muscular* System is the apparatus by which the movements of the body are immediately accomplished ; and these it effects by the peculiar power it possesses, of *contracting* upon the application of certain *stimuli*, of which Nervous Agency is the most powerful.

General Structure and Actions of the Nervous System.

428. The Nervous tissue consists of two distinct structures ; of one of which the *trunks* of the nerves are entirely made up ; whilst the other enters largely into the composition of the *ganglia* or centres of action (§. 65). The former, termed the *white* or *fibrous* tissue, consists of straight fibres, lying side by side, and bound together by areolar tissue into bundles ; these, again, are united with others, into a larger group ; and by the union of a considerable number of such groups, the nervous trunks are formed, which are distributed through the body, especially to the skin and muscles. These fibres, however, differ entirely in their character from any which have been hitherto described. They are found, when examined with a good Microscope, to be *tubes*, containing a sort of pulpy substance, which may be squeezed from their ends when they are cut across. Each of these tubes runs its course completely separated from the rest, no union or

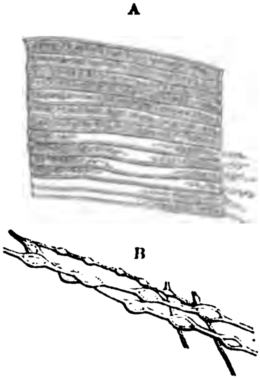

FIG. 168.*—STRUCTURE OF NERVE-TUBES

A, cylindrical tubes from trunk of nerve; B, beaded tubes from brain.

inosculation ever occurring among them: and there is good reason to believe that every tube extends, without break or interruption, from the central organ with which the trunk is connected, to the point at which it enters the muscular substance or skin, to which it is transmitted; and that it has a function entirely distinct from those of the tubes by which it is surrounded.

429. There can be no doubt that the office of *this* kind of Nervous tissue is to *convey* the influence of the changes which are effected in one part of the system, to other and remote parts; just as the wires of a galvanic battery conduct the electric influence, from the instrument which excites it, to some distant point, where it is to be applied to some use. There can be no doubt that the effects of such changes in the state of the Nervous System are propagated in two opposite directions;—the impressions made upon the skin, and other parts possessed of sensibility, being conveyed towards a portion of the nervous centres called the *sensorium*, and there giving rise to *sensations*;—and the influence of the emotions or volitions to which these sensations give rise (§. 7), being propagated *from* the central organs to the *muscles* which they excite to *contraction*. And by the discoveries of Sir C. Bell, hereafter to be described, it has been fully proved that these opposite changes are conducted by two different sets of fibres;—one conveying to the central organs those which originate in the circumference;—and the other conveying to the circumference those which originate in the centre (§. 451). The transmission of these changes is completely interrupted by division of the nervous trunk, or by pressure upon it; and it sometimes happens that one set of conducting fibres is thus affected, whilst the functions of the other are not impaired; so that a limb may possess sensibility, and be totally destitute of the power of motion, or may be completely obedient to the will, though totally destitute of sensibility. In Vertebrated animals, we find some nerves in which there is only one set of fibres; so that the trunk is only sensory or only motor (§. 458): but in general, the two sets are bound up together in the same sheath.

430. The structure and functions of the *gray* substance, however, are very different. This kind of nervous tissue is found in the interior of the ganglia of Invertebrated animals, and in the

centre of the Spinal Cord of Vertebrata; but it is disposed on the outside of the Brain, and forms a thin layer enclosing the fibrous substance, of which the greater part of the mass is composed. From this peculiarity of position in the Brain, it is not unfrequently termed the *cortical* (bark-like) substance. It is principally composed of a minute network of blood-vessels, which surrounds the extremities of the fibres of the white substance; and in the midst of it, there are a large number of cells, that lie loosely in the interstices of the network. What is the precise manner in which this structure acts, we are unable to define; but this much is tolerably certain,—that, in the gray matter of the nervous centres, all those changes originate, which are propagated by the motor fibres to the muscles; and that these changes depend upon the continual supply of arterial blood. If this supply be cut off, by failure of the heart's action (as in ordinary fainting), or by pressure on the vessels that convey blood to the head, immediate insensibility, with loss of all power of motion, is the result.

431. The nervous fibres which are distributed to the muscles, spread forth from their respective trunks in loops, which frequently anastomose with each other, and thus form a network through the muscle. But the fibres which commence in the skin and organs of the senses, and convey the impressions made upon them to the sensorium, do not resemble these in their distribution. They originate in minute elevations of the surface, termed *papillæ;* in every one of which there is a network of vessels, including cells in its meshes, around the extremity of the fibre. The action of the blood conveyed by these vessels is just as necessary for the production of the sensory impression upon the nervous fibre, which is to be conducted by it to the brain, and there to become a sensation,—as it is for the gray matter of the brain to excite a change in the motor fibres that calls a muscle into operation. If the circulation in the skin be checked by cold, or by pressure on the artery of a limb, we perceive a numbness, resulting from the want of power in its nervous fibres to receive impressions. Thus we see that a sort of gray matter exists at the commencement of every sensory fibre, as well as at the com-

mencement of every motor fibre; but that which belongs to the former is diffused over the surface of the body, and the changes to which it gives rise are conducted towards the central organs, there to produce sensations; whilst that which belongs to the latter is collected into a mass, in these same central organs, and its influence is propagated along the fibres which diverge from them to all parts of the body.

432. Hence we find that, before the mind of the individual can become conscious of what is passing around him, a change or *impression* must be effected by external objects upon the origins of the sensory nerves in the papillæ; this impression must be *conducted* by the nervous trunk to the sensorium, and there it becomes a *sensation*. On the other hand, before the mind can direct the body to perform any movement, an *emotion*, or an act of the *will*, must produce a change at the origin of the motor nerves in the brain; and this change is *conducted* along the motor trunks to the muscles, where it excites a *contraction* adapted to the required purpose.

433. It is by actions of this kind, that the Nervous System ministers to those Functions, which are peculiarly distinguished as *Animal* (§. 4). But it is also concerned in producing certain movements of the body, which have for their object to maintain the Organic functions;—those, for instance, of Deglutition (§. 195), and Respiration (§. 340). Such movements require the same double set of nervous fibres, and the same kind of nervous centre containing gray matter; but they do *not* require that *sensation* should intervene, or (in other words) that the individual should become *conscious* of the impression in which they originate, in order that the muscles may be excited to contraction. Movements of this class are termed *reflex;* from the peculiar action of the ganglion in throwing back, or reflecting, along the motor nerves that pass from it, the impressions which it receives from the fibres that pass towards it. There can never be more than a single centre of *sensation* in any animal; for if there were two or more, there must be two sets of feelings, and consequently two distinct individual minds. But there may be many centres of reflex action, having different purposes, because connected

with different functions. In the lower classes of Animals, these centres are often very numerous; and the actions to which they minister, constitute a great part of the movements performed by them. Hence some of our best examples of reflex action are drawn from these classes. But as we ascend the scale, we find that these centres of reflex action are less important in comparison with the organ by which the mind operates; and that the body is more influenced by the latter than by the former. In order to comprehend the mutual relations of the different parts of the nervous system, it will be better to commence with its simplest forms, and to pass gradually on to the more complicated.

Structure and Actions of the Nervous System in the principal Classes of Animals.

434. In most of the **Radiated** classes, it is difficult to discover any distinct traces of a Nervous System; the general softness of their tissues being such, that it cannot be clearly made out amongst them. But in the highest group, the **Echinodermata**, it may be detected without difficulty; and it presents an extremely simple form, which partakes of the general arrangement of parts in these animals. In the *Star-fish*, for instance, it forms a ring, which surrounds the opening into the stomach; this ring consists of nervous cords, which form communications between five ganglia, one of which is placed at the base of each ray. These ganglia appear to be all similar to each other in function. Every one of them sends a large trunk along its own ray; and two small branches to the organs in the central disc. The rays being all similar to each other in structure, it would appear that no one of these ganglia can have any controlling power over the rest. All the rays have at their extremities what seem to be very imperfect eyes; and so far as these can aid in directing the movements of the animal, it is obvious that they will do

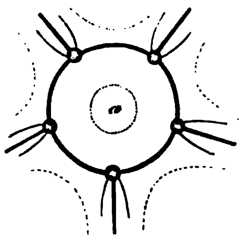

Fig. 169.—Nervous System of Star-fish.
a, position of the mouth.

so towards all sides alike. Hence there is no one part which corresponds to the *head* of higher animals; and the ganglia of the nervous system, like the parts they supply, are but repetitions of one another, and act independently of one another. Each would perform its own individual functions if separated from the rest; but in the entire animal, their actions are all connected with each other by the circular cord, which passes from every one of the five ganglia to those on either side of it. In Man, as well as in all the Vertebrated and Articulated animals, and in some of the Mollusca, there is a like repetition of the parts of the Nervous System, on the two sides of the central line of the body; but the organs are only *double*, instead of being repeated five times. Still the two hemispheres of the brain, and the two halves of the spinal cord, in the Vertebrated animal,—and the two halves of the chain of ganglia, in the Articulated animal,—are as independent of one another as are the five separate ganglia of the Star-fish; and they are made to act in harmony with one another, by similar uniting bands of nervous fibres, which are termed *commissures*.

435. In the nervous system of MOLLUSCA, we do not meet with any such repetition of parts; the body itself not presenting this character. In the lowest and simplest animals of this class, we meet with only a single ganglion, which may be regarded as analogous to any one of the ganglia of the Star-fish; but in the higher, we find the number of ganglia increased, in accordance with the increase of the functions which they have to perform. The simplest form of the nervous system in this class, is seen in the accompanying figure, which represents one of the solitary TUNICATA, the *Ascidia*. At *a* is seen the orifice by which the water enters, for supplying the stomach with food, and aerating the blood (§. 126); and at *b*, is the orifice by which the current of water passes out again, after it has served these purposes. Between these orifices is the single ganglion, *c*, which

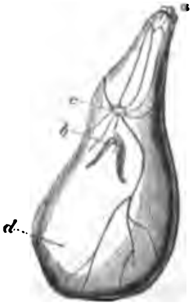

FIG. 170.—NERVOUS SYSTEM OF ASCIDIA.

sends filaments to both of them, and other branches which spread over the surface of the mantle, *d*. These animals are for the most part fixed to one spot, during nearly the whole of their existence; and they show but little sign of life, beyond the continual entrance and exit of the currents already adverted to. When any substance is drawn in by the current, however, the entrance of which would be injurious, it excites a general contraction of the mantle; and this causes a jet of water to issue from both orifices, which carries the offending body to a distance. And, in the same manner, if the exterior of the body be touched, the mantle suddenly and violently contracts.

436. These are the only actions, which, so far as we know, the nervous system of these animals is destined to perform. They do not exhibit the least traces of eyes or other organs of special sense; and the only parts that appear peculiarly sensitive, are the small tentacula which guard the orifice, *a*. It would seem as if the irritation caused by the contact of any hard substance with these, or with the general surface of the animal, caused an *instinctive* contraction of the mantle, having for its object to get rid of the source of the irritation. Such a movement could only be performed by the aid of a Nervous System, which has the power of receiving impressions, and of *immediately* exciting even the most distant parts of the body to act in accordance with them. In the Sensitive Plant, and Venus's Fly-trap (VEGET. PHYS., §. 421, 246), an irritation applied to one part is the occasion of a movement in another; but this takes place slowly, and in a manner very different from the energetic and immediate contraction of the mantle of the Tunicata.

437. In the CONCHIFERA, or animals inhabiting *bivalve* shells, there are invariably two ganglia, having different functions. The larger of these, corresponding to the single ganglion of the Tunicata, is situated towards the posterior end of the body (B, Fig. 171), in the neighbourhood of the posterior muscle; and its branches are distributed to that muscle, the mantle, the gills, and the siphons. But we find another ganglion, or rather pair of ganglia, situated near the front of the body, either upon or at

the sides of the œsophagus; these ganglia are connected with the very sensitive tentacula which guard the mouth; and they evidently correspond, both in their position and functions, to the brain of higher animals, whilst the posterior ganglion has for its office to regulate the respiratory movements. In the *Oyster* and others of the lower Conchifera, which have no foot, these are the only ganglia; but in those which possess a foot, such as the *Pecten*, we find an additional ganglion connected with it. In the accompanying figure of the nervous system of the Pecten, it is seen that the *cephalic* ganglia (or ganglia of the head), A A, are situated beneath the œsophagus, *e*; but are connected with each other by a band that arches over it. They are also connected with the *pedal* ganglion (or ganglion of the foot) C, and with the *branchial* or respiratory ganglion, B; but these last are not connected with each other. In fact, it is found, by careful dissection, that part of the nervous trunks, which pass from the ganglion C into the foot, and from the ganglion B to the respiratory apparatus, originate in the cephalic ganglia; whilst the greater part are connected only with the pedal and branchial ganglia respectively. And there is good reason to believe that, whilst the *cephalic* ganglia alone are the instruments of *sensation* and of *voluntary* power,—so that they exert a general control and direction over the movements of the animal,—the *pedal* and *branchial* ganglia minister to the *reflex* actions (§. 433) of the organs which they supply.

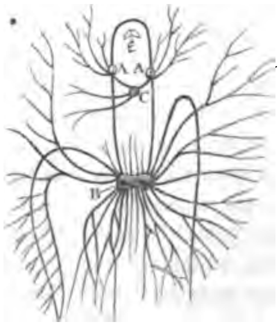

Fig. 171.—Nervous System of Pecten.

A A, cephalic ganglia; B, branchial ganglion; C, pedal ganglion; *e*, œsophagus.

438. A similar arrangement is found in the higher Mollusca, among which the ganglia are more numerous, in consequence of the greater variety of functions to be performed. Of this we have an example in the *Aplysia*, a sort of sea-slug, somewhat resem-

bling those formerly alluded to (316). In proportion as we ascend the scale, we find the cephalic ganglia rising higher and higher on the sides of the œsophagus; and in the Aplysia they meet on the central line above it, forming the single mass A, which receives the nerves of the eyes, tentacula, &c., and sends branches of communication to the other ganglia. The branches which it sends backwards are three on each side. Of these, one passes through the ganglionic masses C C, to communicate with the ganglion B, which is the one connected with the respiratory movements. The others are distributed with the branches of the ganglia C C, the function of which is double; for one set of branches from each is distributed to the mantle in general, every part of which (in these shell-less Molluscs) is capable of contracting and giving motion to the body; whilst another set is distributed to that thick and fleshy part of it which is called its foot, and on which the animal crawls (§. 120). There is another ganglion, D, lying in front of the cephalic ganglion, and also receiving branches of communication from it; this ganglion is specially connected with the actions of mastication and swallowing; and is called the *pharyngeal* ganglion.

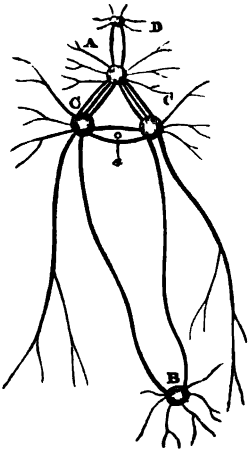

FIG. 172.—NERVOUS SYSTEM OF APLYSIA.

439. Thus we see that the cephalic ganglion sends branches to all the other ganglia; though these, having different functions, do not communicate with each other: and every branch from the cephalic ganglia is distributed, with those of the ganglion it enters, to the organs supplied by the latter. Hence every part has two sets of nervous connections; one with the cephalic ganglia; and the other with its own ganglion. By the former, the animal becomes *conscious* of impressions made upon it, these impressions being converted in the cephalic ganglia into *sensa-*

tions; and the influence of its *instincts* or its *will* is exerted through them, upon the several parts of its body, causing *spontaneous motion.* By the latter are produced those *reflex* actions of the several organs, which do not require sensation or will, but which depend upon the simple conveyance of an impression *to* the ganglion, and the transmission of a motor impulse excited in it, *from* it to the muscles supplied by its nerves. Of these movements in the Mollusca we know but little; in the Articulata, however, they are extremely remarkable.

440. We have seen that, in the Mollusca, a small part only of the Nervous System ministers to the general movements of the body; and this corresponds with what has been elsewhere stated (§. 75) of the inertness which is their general characteristic, and of the small amount of muscular structure which they possess. On the other hand, in the ARTICULATED classes, in which the apparatus of movement is so highly developed, and whose actions are so energetic, we find the Nervous System almost entirely subservient to this function. Its usual form has been already described (§. 71) as a chain of ganglia connected by a double cord, which commences in the head, and passes backwards through the body. In general, we find a ganglion (or rather a pair of ganglia united on the middle line) in each segment; hence in the ANNELIDA and MYRIAPODA, the ganglia are very numerous; but they are proportionably small. In INSECTS, the number of segments, and consequently of ganglia, never exceeds thirteen; and the ganglia are larger.—Whatever be the number of the ganglia, they are usually but repetitions of one another, the functions of each segment being the same with those of the rest. The nerves proceeding from them are chiefly distributed to the muscles of the legs; or, where these do not exist (as in the Leech), to the muscles that give motion to the body. This is the case in the Larva of

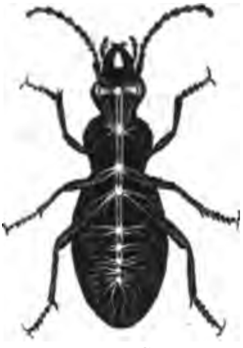

FIG. 173.—NERVOUS SYSTEM OF AN INSECT.

the insect, as in the Centipede, or Nereis; but in the perfect Insect the case is different; for the apparatus of locomotion is confined to the thorax (§. 103), and the segments of the abdomen have no members. We accordingly find that the ganglia of the thorax, from which the legs and wings are supplied, are very much increased in size, and are sometimes concentrated into one mass; whilst those of the abdomen are very small, one or two of them occasionally disappearing altogether.

441. A good example of this curious change in the nervous system of Insects is seen in the *Sphinx ligustri*, or Privet Hawk-Moth, as shown in the accompanying diagrams. In Fig. 174 the nervous system of the Caterpillar is represented; this consists of a pair of cephalic ganglia (1); from which proceeds, on each side, a cord of communication to the first ganglion of the trunk (2), and thence to the other ganglia (3—13). No difference is seen in these ganglia, except that the two last are more closely connected than the rest. The cephalic ganglia, with their cords of communication, form a ring, through which the œsophagus passes; *they* are situated *above* it; but in consequence of the reversed position of Articulated animals, the whole chain of ganglia of the trunk is situated *beneath* the alimentary canal (§. 72).—In Fig. 175 is shown the Nervous System of the perfect Insect; in which it is seen that the whole is considerably shortened (the body of the Moth being much shorter than that of the Caterpillar), and that great changes have taken place in the relative sizes of the ganglia. The cephalic ganglia, being now connected with much more perfect eyes and other organs of sense, are greatly enlarged; the thoracic ganglia, from

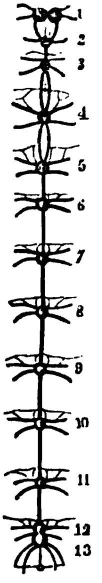

FIG. 174.—NERVOUS SYSTEM OF LARVA OF SPHINX LIGUSTRI.

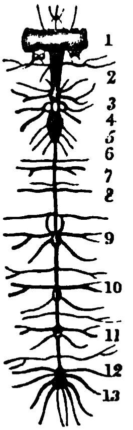

FIG. 175.—NERVOUS SYSTEM OF SPHINX LIGUSTRI.

which the legs and wings are supplied, are enlarged and concentrated; whilst the abdominal ganglia are relatively diminished in size, the 7th and 8th being entirely wanting.

442. When the structure of the chain of ganglia is more particularly inquired into, it is found to consist of two distinct *tracts;* one of which is composed of nervous fibres only, and passes backwards from the cephalic ganglia, over the surface of all the ganglia of the trunk, giving off branches to the nerves that proceed from them; whilst the other connects the ganglia themselves. Hence, as in the Mollusca, every part of the body has two sets of nervous connections; one with the cephalic ganglia; the other with the ganglion of its own segment. Impressions made upon it, being conveyed by the fibrous tract to the cephalic ganglia, become *sensations;* and by the influence of the *instincts* or *will*, operating through these same ganglia, the general movements of the body are harmonised and directed. It is obvious that, as the motions of an animal are chiefly guided by its sight, the cephalic ganglia would have a governing influence over the rest, if only from their peculiar connection with the eyes; but there is good reason to believe, that their functions are still more different from those of the ganglia of the trunk, and that sensation resides in them alone. The motions produced by the ganglia of the trunk, when separated from the head, are often very remarkable, and *seem* at first sight to indicate sensation and a guiding will; but, when they are carefully studied, it is found that striking differences are to be detected, by which their nature is found to be simply *reflex*,—a certain stimulus or irritation producing a certain movement, without any choice or guidance on the part of the animal, and probably without its consciousness. As there are no animals in which these reflex movements are more remarkable, than in Centipedes and Insects, we shall pause to dwell upon them here in more detail.

443. If the head of a *Centipede* be cut off, whilst it is in motion, the body will continue to move onwards by the action of the legs; and the same will take place if the body be divided into several distinct portions. After these actions have come to an end, they may be excited again by irritating any part of the

nervous centres, or the cut extremity of the nervous cord. The body is moved forwards by the regular and successive action of the legs, as in the natural state; but its movements are always forwards, never backwards; and are only directed to one side when the direct movement is checked by an interposed obstacle. There is not the slightest indication of consciousness; no direction of object; no avoidance of danger. If the body be opposed in its progress, by an obstacle not more than one half its own height, it mounts over it and moves directly onwards, as in a natural state; but if the obstacle is equal to its own height, its progress is arrested, and the cut extremity of the body opposed to it remains in contact, with the legs still moving. If, again, the nervous cord of a Centipede be divided in the middle of the trunk, so that the hinder legs are cut off from connection with the cephalic ganglia, they will continue to move, but not in harmony with those in the fore part of the body,—being completely paralysed as far as the animal's will is concerned,—though still capable of performing reflex movements by the influence of their own ganglia. Or, again, if the head of a Centipede be cut off, and, while it remains at rest, some irritating vapour (such as that of ammonia or muriatic acid) be caused to enter the air-tubes on one side of the trunk, the body will be immediately bent in the opposite direction, so as to withdraw itself as much as possible from the influence of the vapour: if the same irritation be applied on the other side, the reverse movement will take place; and the body may be caused to bend in two or three curves, by bringing the irritating vapour in the neighbourhood of different parts of either side. This movement is evidently a reflex one, and serves to withdraw the entrances of the air-tubes from the source of irritation; just as the act of sneezing in higher animals causes the expulsion from the air-passages of any irritating matter, whether solid, liquid, or gaseous, which may have found its way into them; and we have no reason to regard the former as more voluntary than the latter, which we know to be purely reflex (§. 342).

444. Among Insects, we meet with reflex actions yet more curious. The *Mantis religiosa* (Fig. 176) is remarkable for the

peculiar conformation of its first pair of legs, which serve as claws for seizing its prey; and also for the peculiar attitude which it assumes, especially when threatened or attacked. Supporting itself upon its two hinder pairs of legs, it rears up its head upon the long first segment of the thorax, and thus elevates at the same time its large and powerful arms; the resemblance fancied to exist between this attitude and that of prayer, is the cause of the epithet *religiosa* having been given to it. Now if the first segment of the thorax, with its attached members, be removed, the posterior part of the body will still remain balanced upon the four legs which belong to it; resisting any attempts to overthrow it, recovering its position when disturbed, and performing the same agitated movements of the wings, as when the unmutilated animal is excited. But it will remain quite at rest, so long as it is not irritated. On the other hand, the detached portion of the thorax, which contains a ganglion, will, when separated from the head, set in motion its long arms, and impress their hooks on the fingers which hold it.—Again, a specimen of *Dytiscus* (a Water-Beetle), from which the cephalic ganglia had been removed, executed the usual swimming motions, when cast into water, with great energy and rapidity, striking all its comrades to one side by its violence; in these it persisted for half an hour; but, whilst previously lying on a dry surface, no such movements were excited.

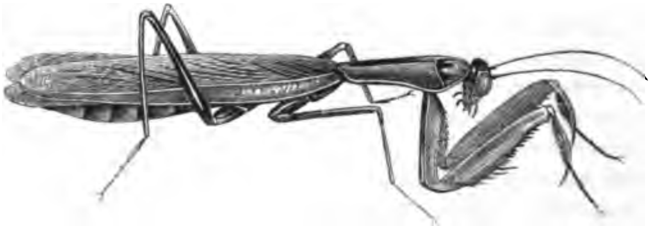

FIG. 176.—MANTIS RELIGIOSA.

445. From these and similar facts it appears, that the ordinary movements of the legs and wings of Articulated animals are of a reflex nature, and are dependent only upon the ganglia with

which these organs are severally connected; whilst in the perfect animal, they are harmonised, controlled, and directed by its instinct or will (guided by its sensations), which act through the cephalic ganglia and the trunks proceeding from it. When we come to compare the reflex movements of Insects with those of the higher animals, we shall perceive that there is no necessity to suppose the ganglia of the trunk to be in *themselves* endowed with sensibility; so that, when the head is cut off, or the cephalic ganglia are removed, or their connection with any part of the body is interrupted by division of their nervous cord, no *sensation* is felt, however much the movements it performs may seem at first to indicate this. (See §. 467.)

446. From this account of the structure and uses of the chain of ganglia in the Articulata, it is obvious that these ganglia are so many repetitions of the *pedal* ganglia (or ganglion of the foot) of the Mollusca; and we have not yet had to notice any ganglia appropriated to other functions. In Fig. 175, however, is seen a small ganglion in front of the cephalic mass, which corresponds to the *pharyngeal* ganglion of the Aplysia (Fig. 172, D); and we have now to describe an entirely distinct system of nerves, appropriated to the function of *respiration*. As the respiratory apparatus of Articulata, instead of being confined to one spot, as is that of the Mollusca, is dispersed through the body (§§.316 and 320), the ganglia which minister to its actions are repeated in the several segments. There is, in fact, a chain of minute ganglia lying upon the larger cord, and sending off its nerves between those proceeding from the latter, as is seen in Fig. 174. These respiratory ganglia and their nerves are best seen in the front of the body, where the cords that pass between the ganglia diverge or separate from each other. This is shown on a larger scale in Fig. 177; where A B, A B, are two pairs of ganglia in the thoracic region, connected by two cords which diverge from one another; and between these are seen the small respiratory ganglion *a*, and its branches *b*, *b*. These branches are distributed to the air-tubes and other parts of the

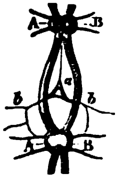

FIG. 177.—PORTION OF THE NERVOUS SYSTEM OF INSECT, showing the respiratory ganglia and nerves.

respiratory apparatus; and communicate with those of the other system. We shall find that, even in the highest Vertebrata, there is a portion of the nervous centres, which is set apart for the maintenance of the respiratory actions, and which may be regarded as the respiratory ganglion; though it is so closely connected with other parts of the mass, as to seem but a part of it (§. 450).

447. In the higher Invertebrata, both among the Articulated and Molluscous classes, we find a tendency to the concentration of the ganglia into one or two masses,—carrying to a greater extent that which has been already noticed in the perfect Insect (§. 441). Thus in the *Spider*, the cephalo-thorax contains a single large ganglion (*t*, Fig. 46), from which all the legs are supplied. The same is the case in the *Crab*, whose nervous system is represented in Fig. 178. Besides this mass, *t*, however, which is situated beneath the alimentary canal, there is a single or double cephalic ganglion, *c*, which receives the nerves from the organs of sense, and sends backwards, to communicate with the mass, *t*, a pair of cords that separate to give passage to the œsophagus, round which they form a sort of collar, *co*. And there are other small ganglia and nerves, connected with the operations of mastication and digestion; these are called *stomato-gastric* (from two Greek words, meaning the mouth and the stomach).

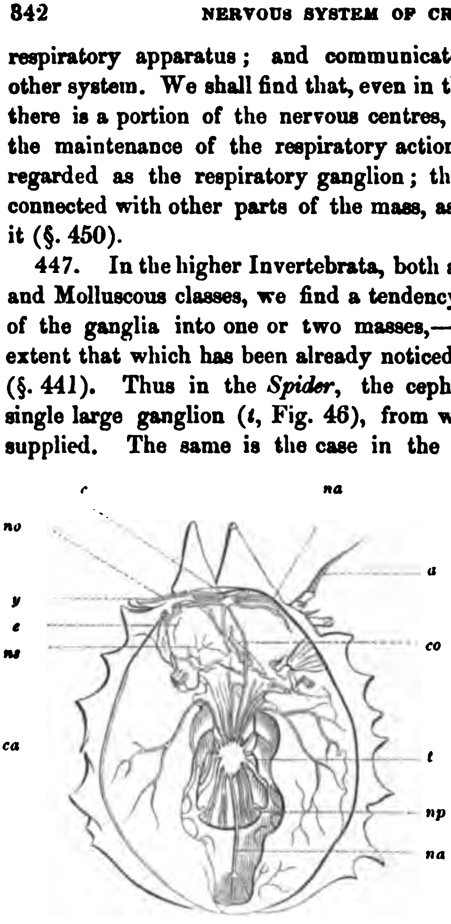

Fig. 178.—Nervous System of Crab (*Maia*). *ca*, upper part of the shell laid open; *a*, antennæ; *y*, eyes; *e*, stomach; *c*, cephalic ganglion; *no*, optic nerves; *co*, œsophageal collar; *ns*, stomato-gastric nerves; *t*, thoracic ganglionic mass; *np*, nerves of the legs; *na*, abdominal nerve.

448. A similar concentration, though with a different arrangement of parts, is seen in the nervous system of the *Poulp*, one of the Cephalopoda (§. 61). There is still a nervous collar through which the œsophagus passes (*a*, Fig. 179); but, the organs of locomotion being the enlarged tentacula that surround the mouth, the nerves given off to them arise from ganglia, that form part of the cephalic mass, *b*, *b*, instead of being located at a distance from it. At *o* are seen the optic nerves, proceeding from distinct ganglia; and at *c* is a ganglionic mass which seems to bear more resemblance to the proper brain of higher animals, than does any that we elsewhere find in the Invertebrata. In front of this are two ganglia on the middle line, both of which belong to the *stomato-gastric* system, one supplying the lips and the other the pharynx. From the mass, *g*, situated beneath the œsophagus, there pass backwards two cords *m m*, each of which has a ganglion *e* upon its course, and from this are given off nerves to the general surface of the mantle;

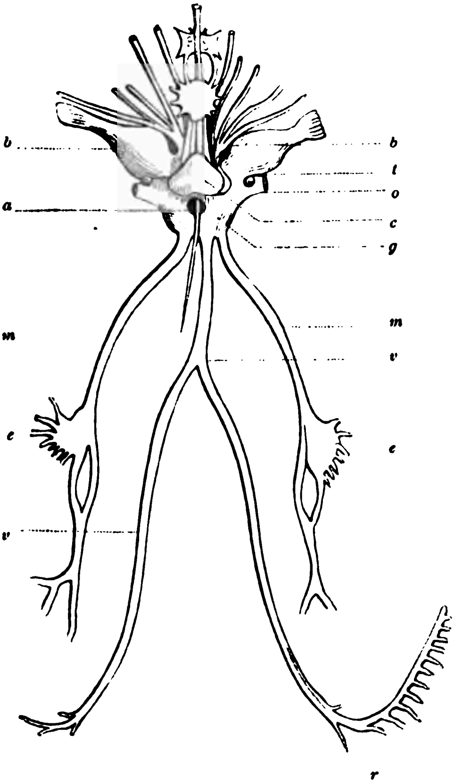

FIG. 179.—NERVOUS SYSTEM OF OCTOPUS (Poulp).

and also other two cords, which run backwards to supply the viscera, and especially the gills,—each passing through a small long ganglion, *r*, before entering them. It would seem as if the ganglia *e* and *r* corresponded with the ganglia C and B in the Aplysia; but as if, in consequence of the great enlargement of the cephalic mass, they were proportionally reduced in size.

449. In the nervous system of Vertebrated animals, the ganglia are no longer scattered through the body; but are united into one continuous mass; and this mass, known as the *brain* and *spinal cord*, is enclosed within the bony casing formed by the skull and vertebral column, in such a manner as to be protected by it from injuries to which it would otherwise be continually liable (§. 64, 65). We have seen that, among the Invertebrated classes, the nervous system has no such peculiar defence, but lies among the other organs, sharing with them the protection afforded by the general hard envelope of the body. But in the Vertebrata, its development is so much higher, and its importance so much greater, that special care is taken to guard it from injury.—The term *brain* is commonly applied to the whole mass of nervous matter contained within the cavity of the skull; but this consists of several distinct parts, which have obviously different characters. The principal mass in Man and the higher Vertebrata is that which is termed the *Cerebrum* (*a*, Fig. 184); this occupies all the front and upper part of the cavity of the skull, and is divided into two halves or *hemispheres*, by a membranous partition which passes from back to front along the middle line. Beneath this, at the back part of the skull, is another mass, much smaller, but still of considerable size, termed the *Cerebellum* (*b*, Fig. 184); and this also is divided into two hemispheres. At the base or under side of the cerebrum, and completely covered in by it, are two pairs of ganglia, which belong to the nerves of smell and sight (1 and *g*, Fig. 185). We shall presently find that these are, relatively speaking, much larger in the lower Vertebrata than in the higher.

450. The several masses of nervous matter contained in the skull are connected with each other, and with the spinal cord,

by bands of nervous fibres; in fact, a considerable part of the spinal cord consists of bundles of fibres issuing from the skull, to be distributed to the several parts of the body. But the spinal cord has also distinct properties of its own, which show that it is to be regarded as analogous to the chain of ganglia in Insects, or to the ganglia scattered through the bodies of the Mollusca. The upper part of it, which passes up into the cavity of the skull, is termed the *Medulla Oblongata* (*f'*, Fig. 186). This is connected with the nerves of respiration, mastication, and deglutition; and may be regarded as combining together the *respiratory* and *stomato-gastric* ganglia of the Invertebrata. The remainder of the spinal cord, which descends through the vertebral column, sends its nerves to the limbs and trunk; and may be regarded as analogous to the chain of ganglia by which the corresponding parts are supplied in Insects.

451. The nerves which issue from the Spinal Cord, all possess two sets of roots; one from the *anterior* portion of the cord, the other from its *posterior* portion (Fig. 180). The fibres which come off by these two sets of roots soon unite into the trunk of the nerve; which thus possesses the properties common to both. It has been ascertained by numerous experiments, that the *posterior* set of roots consists of those fibres that bring impressions *from* the body in general *to* the Spinal Cord; which impressions, if they are carried on to the Brain, become *sensations*. On the other hand, the *anterior* roots consist of fibres which convey motor influence *from* the Spinal Cord and Brain, *to* the muscles of the body. Thus, if the spinal cord of an animal be laid bare, and the *posterior* set of roots be touched, acute *pain* is obviously produced; whilst, if the anterior roots be irritated, violent *motions* of the muscles supplied by that nerve are occasioned. Both these roots contain fibres that connect them with the brain as well as with the spinal cord; so that, through the same trunk, either of these centres may act upon the part. We shall pre-

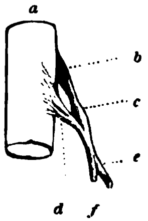

FIG. 180.
PORTION OF THE SPINAL CORD, showing the origin of the nerves: *a*, spinal cord; *b*, posterior root; *c*, ganglion upon its course; *d*, anterior root; *e*, trunk formed by the union of both; *f*, branch.

sently find that there is good reason to believe the *Brain* to be the seat of *sensibility* and *voluntary power;* whilst the *Spinal Cord* is the instrument of those *reflex* actions, which take place mechanically as it were, without direction on the part of the animal, and which are concerned in the maintenance of the organic functions of the body, and in its preservation from injury.

452. The relative proportions which these different parts present, are very different in the several classes of Vertebrata. We find that, among the lower, the *ganglia* connected with the organs of sense (which are analogous to the cephalic ganglia of the Invertebrata) are very large, and occupy a considerable part of the cavity of the skull; whilst the *cerebrum* and *cerebellum* are comparatively small.—The Cerebrum increases, as we ascend the scale, in proportion to the development of the *intelligence*, and the predominance which it gradually acquires over blind undesigning *instinct* (Chap. XIV.). Its greatest development is seen in Man.—The Cerebellum seems to be connected with muscular motion, and to bear a proportion in size with the variety and complexity of the movements which the animal performs, serving to harmonise these and blend them together; and it is largest in those animals which have to be constantly exerting themselves to maintain their balance,—such as Man, and the higher Monkeys.—On the other hand, the Spinal Cord, and the nerves proceeding from it, are largest in those animals in which the brain is smallest.

453. It is in FISHES, that we find the brain least developed, and the cerebral hemispheres bearing the smallest proportion to the other parts. On opening the skull, we usually observe four nervous masses (three of them in pairs) lying, one in front of the other, nearly in the same line with the spinal cord. Those of the first pair are the *olfactory ganglia*, or the ganglia of the nerves of smell (Fig. 181 A, *ol*). In the Shark, and some other Fishes, these are separated from the rest by peduncles or footstalks (B, *ol*); a fact of much interest, as explaining the arrangement which we find in Man (§. 458). Behind these is a pair of ganglionic masses, of which the relative size varies

considerably in different fishes; thus in the Cod, they are much smaller than those which succeed them; whilst in the Shark they are as much larger. These are the *cerebral hemispheres* (*ch*). Behind these, again, are two large masses, *op*, the *optic ganglia*, in which the optic nerves terminate. And at the back of these, overlying the top of the Spinal Cord, is a single mass, the *cerebellum* (*ce*); this is seen to be much larger in the active rapacious Shark, the variety of whose movements is very great, than in the less energetic Cod. The Spinal Cord (*sp*) is seen to be divided at the top by a fissure, which is most wide and deep beneath the cerebellum, where there is a complete opening between its two halves. This opening corresponds to that through which the œsophagus passes in the Invertebrata; but, as the whole nervous mass of Vertebrated animals is above the alimentary canal (§. 66), it does not serve the same purpose in them; and in the higher classes, the fissure is almost entirely closed, by the union of the two halves on the central line.

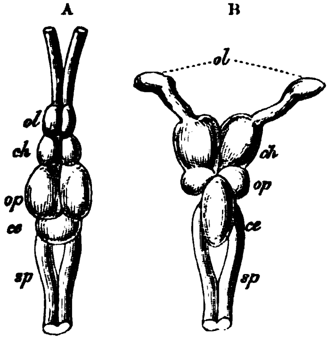

FIG. 181.—BRAINS OF FISHES. A, Cod; B, Shark.

454. In **REPTILES**, we do not observe any considerable advance in the character of the brain, beyond that of Fishes; save that the Cerebral hemispheres are usually larger, extending forwards so as to cover in the Olfactive ganglia (Fig. 182). The Cerebellum is generally smaller, as we should expect from the inertness of these animals, and the want of variety in their movements (§. 480). The Spinal Cord is still very large, in proportion to the nervous masses contained in the skull; and, as we shall hereafter see, its power of keeping up the movements of the body, after it has been cut off from connection with the brain, is very considerable.

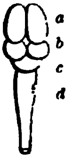

FIG. 182.—BRAIN OF REPTILE. *a*, cerebral hemispheres; *b*, optic ganglia; *c*, cerebellum; *d*, spinal cord.

455. In BIRDS, however, we find a considerable advance in the character of the brain, towards that which it presents in Mammalia. The Cerebral hemispheres (*a*, Fig. 183) are greatly increased in size, and cover in, not only the olfactory ganglia, but also in great part the optic ganglia, *b*. The Cerebellum, *c*, also, is much more developed, as we should expect from the number and complexity of the movements performed by the animals of this class; but it is still undivided into hemispheres. The Spinal Cord, *d*, is still of considerable size, and is much enlarged at the points from which the nerves of the wings and legs originate; in the species whose flight is most energetic, the enlargement is the greatest in the neighbourhood of the wings; but in those which, like the Ostrich, move principally by running on the ground, the posterior enlargement from which the legs are supplied with nerves, is the more considerable.

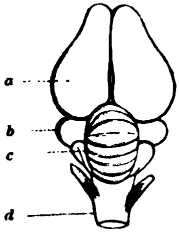

FIG. 183.—BRAIN OF OSTRICH.

456. In the MAMMALIA, we find the size of the Cerebral hemispheres very greatly increased, especially as we rise towards Man; whilst the olfactive and optic ganglia are proportionally diminished, and are completely covered in by them. The surface of the cerebral hemispheres is no longer smooth, as in most of the lower classes, but is divided by furrows into a series of *convolutions* (Fig. 185); by these, the surface over which the blood-vessels come into relation with the nervous matter is very greatly increased; and we find the convolutions more marked as we rise from the lowest Mammalia, in which they scarcely exist, towards Man, in whom the furrows are deepest. The two hemispheres are much more closely connected with each other, by means of fibres running across from either side, than they are in the lower tribes; and in fact, a considerable part of their mass is made up of fibres that pass among their different portions, uniting them with each other. The Cerebellum, also, is divided into two hemispheres (*b*, Fig. 184); and the gray matter in its interior has a very complex and beautiful arrangement, which causes it

to present a tree-like aspect when it is cut across (*d*, Fig. 185).

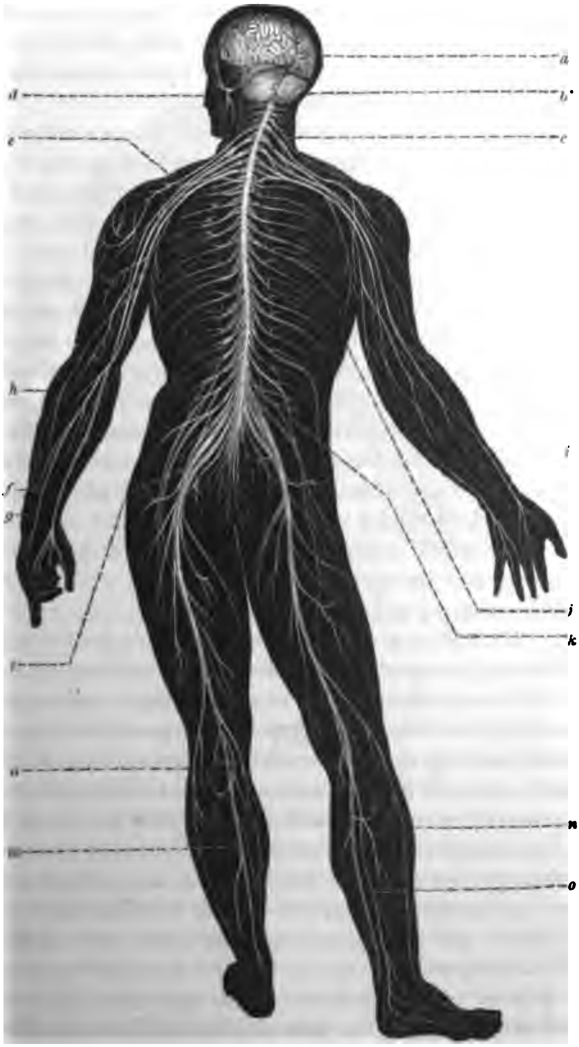

FIG. 184.—NERVOUS SYSTEM OF MAN.

The Spinal Cord is much reduced in size, when compared with the other parts of the nervous centres; the motions of the animal now depending more upon its will, and being more guided by its sensations; and the simply *reflex* actions bearing a much smaller proportion to the rest.

457. The general arrangement of the nervous centres, and distribution of the nervous trunks, of Man, are shown in Fig. 184. At *a* are seen the hemispheres of the Cerebrum; at *b* those of the Cerebellum; and at *c*, the Spinal Cord. The principal motor nerve of the face (the *facial*) is seen at *d;* and at *e* is seen the *brachial plexus*, a sort of network of nerves, originating by several roots from the spinal cord, and going to supply the arm. From this plexus there proceed the *median* nerve, *f;* the *ulnar* nerve, *g;* the *internal cutaneous* nerve, *h;* and the *radial* and *musculo-cutaneous* nerves, *i*. From the Spinal Cord are given off the *intercostal* nerves, *j*, passing between the ribs; the nerves forming the *lumbar* plexus, *k*, from which the front of the leg is supplied; and those forming the *sacral* plexus, *l*, from which the back of the leg is supplied. The latter gives origin to the *great sciatic* nerve; which afterwards divides into the *tibial* nerve, *m;* the *peroneal* or *fibular* nerve, *n;* the *external saphenous* nerve, *o;* and other branches.

458. We shall now examine the structure of the Brain itself, and the arrangement of the nerves which proceed from it; confining ourselves to the points of most importance, and neglecting those which are interesting only to the professed anatomist. The accompanying figure represents a perpendicular section of the Brain, down its middle; separating the two hemispheres, by cutting across the band that unites them. We first remark the very large size of the Cerebrum; which is usually described as consisting of three lobes or divisions,—*a*, the anterior; *b*, the middle; and *c*, the posterior. We notice the convolutions upon the surface of the hemisphere; and the broad band of fibres, *f* (termed the *corpus callosum*), by which it is united to its fellow. At *d* is seen the Cerebellum; with the curious appearance (termed *arbor vitæ*, or the tree of life) which its gray matter exhibits when cut through. At *e* is seen the Spinal Cord; and

at *g* the *optic lobes* or ganglia, buried as it were beneath the cerebral hemispheres. The *olfactory ganglia* are also very small,

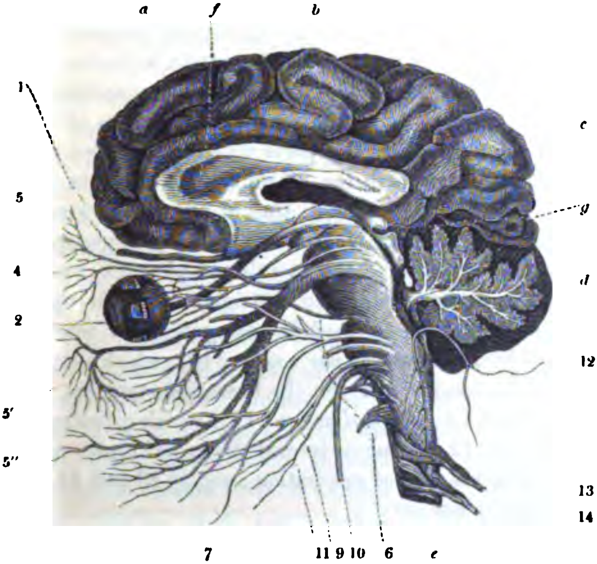

FIG. 185.—SECTION OF THE BRAIN OF MAN.

consisting merely of bulbous enlargements upon the trunk of the *olfactory nerves* (1), which are the first pair given off from the brain. From these bulbous enlargements (which, though covered in by the cerebrum, are separated from it by foot-stalks, as in the Shark, §. 453), are given off the small branches which pass down into the nose, (§. 506). Next to these are the *optic nerves* (2), which may be traced backwards to the optic ganglion, *g*. The *third*, *fourth* (4), and *sixth* pairs (6), are nerves of motion only, and are distributed to the muscles of the eye. The *fifth* pair is for the most part a nerve of sensation only. Before leaving the skull, it divides into three great branches; of which the first (5) passes into the orbit (or cavity in which the eye is lodged), endows the parts contained in it with sensibility, and then comes out beneath the eyebrow, to be distributed to the forehead and temples; the second (5′) passes just beneath the orbit, and makes its way out upon the face, supplying the cheeks, nose, upper lip, &c., which it endows with sensibility; whilst the third (5″), which (like the spinal nerves) possesses a motor root also, supplies the muscles of mastication with the power of moving, and the parts about the mouth with sensibility. The *seventh* pair (7), or *facial*, is the general motor nerve of the face; and this does not endow the parts which it supplies with the least sensibility. Beneath the origin of this nerve is seen the cut extremity of another trunk, that of the *auditory* nerve, or nerve of hearing. At 9 is seen the *glosso-pharyngeal* nerve, which supplies the back of the mouth and pharynx, and is concerned in the act of swallowing. Originating from the upper part of the spinal cord (or *medulla oblongata*) very near this, is the *pneumo-gastric* nerve, or *par vagum* (10), which supplies the lungs and air-passages, and also the heart and stomach. Below this, again, is the *hypoglossal* nerve (11), which gives motion to the tongue; at 12 is a nerve termed the *spinal accessory*, which is concerned in the acts of respiration; and at 13 and 14 are two of the regular spinal nerves.

459. Although several of these nerves seem to come off from the Brain, yet they are all really connected with the Spinal Cord. In fact, it is probable that every one of them, like the spinal nerves (§. 451), contains one set of filaments which communicates with the Cerebral hemispheres; and another set which terminates in the Spinal Cord.

460. A general connected view of the Brain and Spinal Cord is given in Fig. 186; which represents the front of the latter, with the Brain, *a*, turned back, so as to expose its under side. At *b* is seen its anterior lobe; at *c* its middle lobe; and its posterior lobe, *d*, is almost entirely concealed by the Cerebellum, *e*. At *f′* is shown the *Medulla Oblongata*, or upper end of the Spinal Cord, *f f*. The brachial plexus is seen at *g*, formed by the nerves that originate in the cervical region of the cord; at *h* is the lumbar plexus formed by the nerves of the lumbar portion; and at *k* is the sacral plexus formed by the sacral nerves. The spinal cord terminates at its lower extremity

in a bundle of nerves, to which the name *cauda equina* is given, from its resemblance to a horse's tail. The various pairs of nerves from 1 to 14 are the same as in the preceding description; 15 and 16 are nerves from the upper part of the cervical region; 25, a pair from the dorsal region; and 33, a pair from the lumbar region. All these spinal nerves find their way out through apertures in the vertebral column, which are formed by a union of two notches, one in each of the adjoining vertebræ.

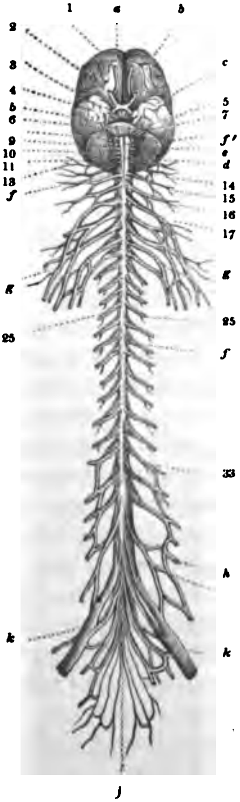

Fig. 186.—Brain and Spinal Cord of Man.

461. The system of nerves which we have been describing is termed the *cerebro-spinal;* but it is not the only set of nerves and ganglia contained within the bodies of Vertebrated animals. In front of the vertebral column there is a chain of oblong ganglia, which communicate with two large ganglia that lie among the intestines, and with several small ganglia in the head and other parts. They communicate also with the posterior roots of the spinal nerves, on which are another set of ganglia (*c*, Fig. 180), that seem to belong to this system. The nerves proceeding from this system, which is called the *sympathetic*, are not distributed, like those of the cerebro-spinal, to the skin and muscles; but to the organs of digestion and secretion, and to the heart and blood-vessels. Hence the former system of nerves, being that by which sensations are received and spontaneous motions executed, is called the *nervous system of animal life;* whilst the latter, being connected with the nutritive processes alone, is termed the *nervous system of organic life.* What is the nature of the influence which it exerts

over the functions of the organs to which it is distributed, is not yet clearly made out. The sympathetic nerves distributed to the alimentary canal have been ascertained to have the power of exciting its peristaltic actions; but they do this in virtue of filaments from the cerebro-spinal system which they contain. Those which are distributed with the blood-vessels (on the coats of which they form a minute net-work) to the glands, seem to have the power of influencing the nature of their secretions; and probably form the channel through which the passions and emotions of the mind affect them (§. 353). We have a familiar example of the influence of these states of mind upon the circulation, in the acts of blushing and turning pale from agitation of the feelings; and a more decided, but less frequent one, in the fainting which sometimes occurs from a sudden shock. It is probable that the Sympathetic system further serves to harmonise and blend together the various actions of nutrition, secretion, &c.; in such a manner as to bring them into conformity with each other, and with the condition of the organs of animal life.

462. Although there is an apparent resemblance between the Sympathetic system of Vertebrata, in regard to the scattered arrangement of its ganglia, and the Nervous Systems of Articulated and Molluscous animals, yet there is no real analogy between them; for the latter, like the Cerebro-Spinal system of Vertebrated animals, are almost exclusively distributed to the organs of animal life; and the mere similarity in the arrangement of the ganglia, is not enough to establish such an analogy, when the difference in their functions is so important.

463. We shall now consider, in more detail, the functions of the different parts of the Cerebro-Spinal System in Man and the higher animals; referring occasionally to the Invertebrated classes, for illustrations which they can best afford. We shall commence by examining the functions of the Spinal Cord and Medulla Oblongata, which are the parts concerned in Reflex Action.

Functions of the Spinal Cord.—Reflex Action.

464. The Spinal Cord of Vertebrated Animals may be considered as a collection of ganglia, analogous to those of which

the ganglionic cord of Articulata is composed; these ganglia being united, however, in an unbroken line, instead of being distinct from one another, and made to communicate by connecting cords. Of the nerves which pass off from the Spinal Cord, some of the fibres (as already stated, §. 451) terminate in the gray matter which occupies its interior; whilst others are continuous with its white or fibrous portions, and pass on through the Medulla Oblongata to the brain. The former set, therefore, constitute the *spinal* portion of the nervous trunks; whilst the latter are to be regarded as their *cerebral* portion. On the principle formerly stated (§. 428) of the separate action of the individual fibres, there can be little doubt that the spinal and cerebral systems of nerves are really as distinct from one another, as if they were separately distributed to the parts which both supply, instead of being (for the sake of convenience, as it would appear) bound together in the same sheath.

465. The *cerebral* system of nerves conveys impressions from every part of the body to the *brain*, where they are communicated to the mind,—that is, the individual becomes *conscious* of them, or *feels* them as *sensations*. And by the fibres of the same system which pass from the brain to the muscles, the *will* acts upon these in producing *voluntary* motion. Now the brain is not in constant action, even in a healthy person; it requires rest; and during profound sleep, it is in a state of complete torpor. Yet we still see those movements continuing, which are essential to the maintenance of life,—the breathing goes on uninterruptedly,—liquid poured into the mouth is swallowed,—and the position is changed, when the body would be injured by remaining in it. The same is the case in apoplexy, in which the actions of the brain are suspended by pressure upon it. And the same will take place, also, in an animal from which the cerebrum has been removed; or in which its functions are completely suspended by a severe blow on the head. If the edge of the eye-lid be touched with a straw, the lid immediately closes. If a candle be brought near the eye, the pupil contracts (§. 534). If liquid be poured into the mouth, it is swallowed. If the foot be pinched, or burnt with a lighted taper, it is withdrawn; and,

if the experiment be made upon a Frog, the animal will leap away, as if to escape from the source of irritation. The respiratory movements, too, are kept up with regularity; so that there is no impediment to the continuance of the circulation, and the *organic* life of the animal may thus continue for some time. In one of the experiments made with the view of ascertaining the degree, in which the activity of the cerebrum is essential to the maintenance of life, a pigeon was kept alive (if alive it could be called) for some months after the removal of its cerebrum,—running when it was pushed, flying when it was thrown into the air, drinking when its beak was plunged in water, swallowing food which was put into its mouth,—but at all other times, when left to itself, appearing like an animal in profound sleep.

466. It is evident, therefore, that we are not to regard the Brain (according to the former opinion of Physiologists, and the belief which is still commonly entertained) as the only centre of nervous power, and as essential to the maintenance of the life of the body; and that we must attribute to the Spinal Cord no small amount of independent power. We might be disposed to infer, from the statements in the last paragraph, that an animal whose brain has been removed, can still feel and judge and perform voluntary motions, by means of the Spinal Cord; but this, again, would be putting a wrong interpretation upon the phenomena in question. It is observed that the motions performed by an animal in such circumstances are *never spontaneous;* they are always *excited* by a stimulus of some kind. Thus a decapitated Frog, after the first violent convulsive movements occasioned by the operation have passed away, remains at rest until it is touched; and then its leg, or even its whole body, will be thrown into sudden action, which immediately subsides again. In the same manner, the action of swallowing is not performed, except when it is excited by the contact of food or liquid (§. 195); and even the respiratory movements, spontaneous as they seem to be, would not continue, unless they were excited by the presence of venous blood in the vessels—especially in those of the lungs. These movements are all *necessarily*

linked with the stimulus that excites them;—that is, the same stimulus will always produce the same movement, when the condition of the body is the same. Hence it is evident, that the judgment and will are not concerned in producing them; but that they may be rather compared to the movements of an automaton, which are produced by touching certain springs.

467. The next question is, whether these movements can be performed without any *feeling* or *sensation*, on the part of the animal, of the cause that produces them; and it is rather less easy to give a positive answer to this, either in the affirmative or negative. It is difficult to imagine that an animal performing such regular and various actions, which so strongly resemble those it would execute in its complete state, and which seem so perfectly adapted to their obvious purposes, can be destitute of sensation; and accordingly some Physiologists have regarded them as furnishing proof, that the Spinal Cord possesses the property of sensibility; or, in other words, that an animal whose Brain has been removed, can still *feel*. But this inference will not bear a close examination. Such movements take place, not only when the Brain has been removed and the Spinal Cord remains entire, but even when the Spinal Cord has been itself cut across into two or more portions. Thus if the head of a Frog be cut off, and its Spinal Cord be divided in the middle of the back, so that its fore-legs remain connected with the upper part, and the hind-legs with the lower, each pair of members may be excited to movement by a stimulus applied to itself; but the two pairs will not execute any consentaneous motions, as they will do when the Spinal Cord is undivided. Or, when the Spinal Cord is cut across, without removal of the brain, the *lower* limbs may be *excited* to movement, though completely paralysed to the *will;* whilst the *upper* remain under the control of the animal's sensation, judgment, and volition.

468. Now although the Frog cannot *tell* us that it has no sensation in its lower limbs, we have the strongest possible reason to believe so; for cases are of no infrequent occurrence in Man, in which the Spinal Cord has been injured, in the middle of the back, by disease or accident; and in these, there is not only loss

of voluntary control over the motions of the legs, but loss of sensation also. Further, in several cases of this kind, in which the injury was confined to a small portion of the cord, and the part below was not seriously disturbed, it has been recently noticed, that motions may be *excited* in the limbs, by stimuli applied directly to them,—as, for instance, by tickling the sole of the foot, pinching the skin, or applying a hot plate to its surface;—and this without the least sensation, on the part of the patient, either of the cause of the movement, or of the movement itself; the nervous fibres, which would otherwise have conveyed the impression to the brain, and there given rise to sensation, being interrupted in their course up the spinal cord.

469. By such cases, then, it appears to be clearly proved, that the actions performed by the Spinal Cord, when the Brain has been removed, or its power destroyed, or its communication with the part cut off, *do not depend upon Sensation*; but upon a property peculiar to the Spinal Cord, by which impressions, made upon certain parts, *necessarily* excite motions of an automatic character. By other experiments it has been shown to be necessary for the exercise of this *Reflex* function (as it has been termed), that an impression should be conveyed by one set of nervous fibres, *from* the point where the stimulus is applied, *to* the Spinal Cord; and that a motor impulse should issue *from* the Cord *to* the muscles, being conveyed by another set of filaments. The *excitor* and *motor* filaments distributed to any part are commonly bound up in the same trunk, and are connected with the same part of the Spinal Cord; so that, if this portion or segment be completely separated from the rest, it may still execute the reflex movements of the parts to which its nerves are distributed;—just as a single segment of a *Centipede* will continue to move its legs, provided its own ganglion is entire (§. 443).

470. But in other instances it happens, that we can more clearly distinguish the excitor and motor nerves, from their being distributed separately, and being connected with distinct portions of the spinal cord. Thus in the act of *deglutition* (§. 195), the chief excitor nerve is the *glosso-pharyngeal* (§. 458); this conveys the impression made by the contact of food with the

pharynx, to the Medulla Oblongata; but it does *not* convey the motor influence to the muscles, this being accomplished by branches of another nerve, the *pneumo-gastric*. If the trunk of the glosso-pharyngeal nerve be pinched, an act of deglutition is made to take place; but if it be separated from the Medulla Oblongata, or the pneumo-gastric nerve be divided, or the Medulla Oblongata itself be destroyed, the movement can no longer be thus excited. Hence we see the necessity of the completeness of this nervous chain or circle,—consisting of the nerve proceeding from the part stimulated *to* the ganglion, the ganglion itself, and the nerve proceeding *from* the ganglion to the muscles acted on,—in order that any such reflex movements may be produced.

471. The functions of the Spinal Cord appear to be wholly restricted to the performance of movements of this character; for our knowledge of the nature of which, we are principally indebted to Dr. Marshall Hall. The proportion they bear to the motions which are dependent upon sensation and will, varies greatly in different animals; and it may be judged of with tolerable accuracy, by comparing the relative sizes of the spinal cord and brain. Thus in the lowest Fishes, the spinal cord seems the principal organ, and the brain an insignificant appendage to it. In Man, on the contrary, the spinal cord is so small in comparison with the brain, as to have been regarded (though incorrectly, as we have seen) in the light of a mere bundle of nerves proceeding from it. In the former, the ordinary movements of the body seem principally to depend upon the spinal cord, being only controlled and directed by the brain; just as those of Articulated animals are chiefly dependent upon the ganglia of the trunk, being only *guided* by those of the head (§. 442). But in Man, those only are left to the spinal cord, which are necessary for the maintenance of life; the ordinary motions of the body being for the most part voluntary. Still, as we have just now seen (§. 468), reflex movements may be excited through the spinal cord, even in Man, when the influence of the will is cut off; and it is curious to observe, that the stimulus is most powerful when it acts upon the soles of the feet, and that it ceases to

produce the same effect, when, by the restoration of the functions of the injured part of the cord, the power of the will over the limbs, and also their sensibility, are regained. It would not seem improbable that, when we are walking steadily onwards, and the mind is intently occupied upon some train of thought which takes up its whole attention, the movements of the limbs may be kept up by reflex action. There are few persons to whom it has not occasionally happened, that on awaking (as it were) from their reverie, they have found themselves in a place very different from that to which they had intended going; and even when the mind is sufficiently on the alert to guide, direct, and control the motions of the limbs, their separate actions appear to be performed without any direct exertion of the will, and probably depend, therefore, rather upon the reflex function of the spinal cord, than upon the continual influence of the brain.

472. Besides the reflex movements of deglutition and respiration, which have been formerly considered (§. 195 and 340), and those of locomotion, on which we have now dwelt sufficiently, there are several others of a similar character, all of which have for their object the supply of the wants of the body, or its preservation from injury. It would be unsuitable to the character of this Treatise, however, to enter upon a detailed account of these; and the only one which will be further noticed, is that of *sucking*, as performed by the young Mammiferous animal. In this operation there is a very complex union of the actions of different muscles,—those of respiration, together with those of the tongue and lips. So beautifully adapted is this combination to its designed purpose, that it could not be better contrived by the longest experience or the most careful study. Yet we find that the young animal commences to perform it, without any experience or study, the instant that its lips touch the nipple of its parent. And that it is a *reflex* action, dependent upon the spinal cord alone for its performance, and requiring a stimulus to excite it, is proved by these remarkable facts;—that it has been performed by human infants, which have been born destitute of brain, and which have lived

for some hours; and also by puppies, whose brain had been removed. These last not only sucked a moistened finger, when it was introduced between their lips, but also pushed out their feet, as the young animal naturally does against the mammary glands of the parent.

473. There are many *irregular* actions of the Spinal Cord, however, the careful study of which is of the highest importance to the Medical Man. It is probable that *all convulsive movements* are produced through its agency; for it has been ascertained, by repeated experiments, that these movements are never produced by wounds of the Cerebrum. They are for the most part of a reflex character; that is, dependent upon some stimulus or irritation, which acts through the nervous circle described in §. 470. Thus, convulsions are not unfrequent in children, during the period of teething; and are then produced by the irritation, which results from the pressure of the tooth, as it rises against the unyielding gum (§. 174). They are often occasioned, too, by the presence of indigestible or injurious substances, or of intestinal worms, in the alimentary canal; and will cease as soon as this is properly cleared out. Or, again, in Tetanus or Lock-jaw, resulting from a lacerated wound, the irritation of the injured nerve is the first cause of the convulsive actions; and a similar local irritation is often the origin of Epileptic fits. When these complaints prove fatal, it is usually by suffocation,—the muscles of respiration being fixed by the convulsive action, in such a manner that air cannot pass either in or out.

474. In other forms of convulsive diseases, however, the cause of irritation may directly affect the Spinal Cord, instead of being conveyed to it by the nerves from a distance. This seems to be the case, for example, in Hydrophobia; which terrible complaint is probably due to a poison introduced into the blood, by the bite of the rabid animal, and conveyed by it to the nervous centres. There are other states, too (especially the severer forms of Hysteric disorder), in which the whole Spinal Cord appears to be in an extremely excitable state; so that the slightest stimulus will produce the most violent convulsive actions, and these will succeed one another in extraordinary variety. By

knowing, as we now do, the part of the nervous system on which these convulsive movements depend, the Physician is enabled to apply his remedies with much greater precision than heretofore, and to form a much more accurate estimate of the danger which attends them.

Functions of the Ganglia of Special Sense.—Instinctive Actions.

475. It has been seen that the nerves of *special sense*,—those of smell, sight, and hearing,—terminate in ganglia peculiar to themselves; which ganglia are lodged within the skull, and form part of what is commonly termed the brain, though distinct both from the Cerebrum and the Cerebellum. These ganglia are almost the only representatives of the brain, in the Invertebrated animals; and in Fishes they bear a very large proportion to the other parts, their relative size gradually diminishing as we ascend the scale towards Man. Now when we study the actions of these lower tribes of animals, we find that those which evidently depend upon *sensation*, especially the sense of sight, are still very far from being of the same spontaneous or voluntary character, as those which *we* perform. We judge of this by their unvarying nature,—the different individuals of the same species executing precisely the same movements, when the circumstances are the same,—and this evidently without any choice, or intention to fulfil a given purpose, but under the impulse of an untaught *instinct*. Of this we cannot have a more remarkable example, than is to be found in the operations of Bees, Wasps, and other *social* Insects; which construct habitations for themselves, upon a plan which the most enlightened human intelligence could not surpass; yet which do so without hesitation, confusion, or interruption,—the different individuals of a community all labouring effectively for one common purpose, because their instincts are the same.

476. In higher animals we may often notice the effect of similar instincts, by which the various species are guided in their choice of food; in the construction of their habitations, in their migrations, &c.; but these are frequently modified, to a certain degree, by the *intelligence* which they possess. Thus among

Birds, whose instincts are more remarkable than those of any other class of Vertebrated animals, we find a degree of variation in their plans, and especially an adaptation of means to ends under unwonted circumstances, which we do not meet with among Insects. Of the very remarkable instincts which guide them in the construction of their habitations, some examples will be given hereafter (Chap. XIV). As an illustration of pure untaught instinct among Vertebrated animals, we cannot select a better example than the mode in which a little Fish, termed the *Chætodon rostratus* obtains its food. Its mouth is prolonged into a kind of beak or snout, through which it shoots drops of liquid at Insects that may be hovering near the surface of the water, and rarely fails in bringing them down. Now according to the laws of Optics, the Insect, being above the water whilst the eye of the Fish is beneath it, is not seen by it in its proper place; since the rays do not pass from the Insect to the Fish's eye in a straight line (§. 528). The Insect will *appear* to the Fish a little above the place which it really occupies; and the difference is not constant, but varies with every change in the relative positions of the Fish and the Insect. Yet the wonderful instinct with which the Fish is endowed, leads it to make the due allowance in every case; doing that at once, for which a long course of experience would be required by the most skilful Human marksman, under similar circumstances.

477. The Intelligence and Will of Man in a great degree supersede his Instinctive tendencies; in the same manner as they hold in subordination his reflex movements (§. 471). These Instincts manifest themselves, however, in the form of *desires*, which impel his reason to take measures for their gratification (such, for example, as the desire for food); and also in the form of *emotions*, which produce particular actions of the body, independently of the will, or even in opposition to it. Thus, we see or hear something ludicrous, which involuntarily produces laughter, although we may have the strongest motives for desiring to restrain it. On the other hand, a loathsome object which excites the feeling of disgust, produces nausea and even vomiting. Or, again, a violent fright not unfrequently occasions convulsive

movements; and these may be brought on, in some excitable states of the nervous system (§. 474) by emotions of a less powerful kind.

478. That the Emotions, when they thus affect the body, do not operate through the same set of nervous fibres as those which convey the influence of the Will, seems proved by this fact,—that cases have occurred in which muscles have been paralysed to the Will (their nervous connection with the Cerebrum having been interrupted), whilst they remained obedient to the Emotions; and *vice versâ*. Thus, in one instance, the muscles of one side of the face were palsied in such a manner, that the individual could not *voluntarily* close his eye, nor draw his mouth towards that side; yet, when any ludicrous circumstance caused him to laugh, their usual play was manifested in the expression of his countenance. And in another case, the muscles were obedient to the will; but when the individual laughed or cried under the influence of an emotion, it was only on one side of his face. To these may be added a case, in which the right arm was completely palsied, so that the individual had not the least voluntary power over it; yet it was violently agitated whenever he met a friend whom he desired to greet. These and similar cases afford sufficient proof, that the Will, and the Emotions or Instincts, do not act on the muscles by the same channel;—a fact of great interest and importance.

479. It is evident that, as the nervous fibres which convey the influence of the Instincts and Emotions are different from those which act in obedience to the Will, they must have distinct terminations in the central organs; and when we compare the mental operations of different animals with the development of the ganglionic masses within the head, we are led to perceive a certain correspondence, which leaves but little doubt as to the parts by which these functions are respectively performed. The *cephalic ganglia* of Insects and Mollusca are not analogous to the *whole brain* of the higher Vertebrata; being little else than a collection of ganglia of special sense, chiefly those of the eye,—the senses of smell, taste, and hearing, being in these animals but little developed. Nearly all the actions of Invertebrated

animals, which are not *reflex*, are *instinctive*, and are guided by the sensations received through their eyes. Hence these *optic* and other ganglia may be justly regarded as their centre or seat. In the Cuttle-fish we have seen that a nervous mass is superadded to these (§. 448); which is probably the first rudiment of the Cerebrum. In Fishes, the Cerebrum gains a higher development; but the Optic and other ganglia of special sense still constitute the largest part of the nervous centres contained in the skull. As we ascend towards Man, the Cerebrum steadily increases in size, and in complexity of structure; and in the same proportion the other ganglia diminish; and as we observe the *Intelligence* and *Will* increasing in power, whilst the *Instincts* become less and less remarkable, in a corresponding proportion, there can scarcely be a doubt that the Cerebrum is the instrument of the former, whilst the Optic and other ganglia of special sense are the centres through which the latter are performed.

Function of the Cerebellum.—Combination of Muscular Actions.

480. Much discussion has taken place of late years, respecting the uses of the Cerebellum; and many experiments have been made to determine them. That it is in some way connected with the powers of *motion*, is now generally admitted. It has been already pointed out, that its size in the different tribes of Vertebrated animals bears a pretty close correspondence with the variety and energy of the movements performed by them (§. 452); and that it is the largest in those animals, which require the constant united effort of a large number of muscles, to maintain their usual position; whilst it is smallest in those, which require no muscular exertion for this purpose. Thus in animals that habitually rest and move upon four legs, there is but little occasion for any organ to combine and harmonise the actions of their several muscles; and in these, the Cerebellum is small. But among the more active predaceous Fishes (as the Shark),—Birds of most powerful and varied flight (as the Swallow, which not only flies rapidly, but executes the most complicated evolutions in pursuit of its Insect prey with the greatest facility),—and Mammalia which can maintain the erect position, and use their

extremities for other purposes than support and motion,—we find the Cerebellum of much greater size; and in Man, who surpasses all other animals in the number and variety of the combinations of muscular movement which he is capable of executing, it attains its largest dimensions.

481. From experiments upon all classes of Vertebrated Animals, it has been found that, when the Cerebellum was removed, the power of walking, springing, flying, standing, or maintaining the equilibrium of the body, was destroyed. It did not seem that the animal had in any degree lost *voluntary* power over its individual muscles; but it could not combine their actions for any general movement of the body. The *reflex* movements, such as those of respiration, remained unimpaired. When an animal in this state was laid on its back, it could not recover its former posture; but it moved its limbs or fluttered its wings, and evidently was not in a state of stupor. When placed in the erect position, it staggered and fell like a drunken man,—not, however, without making efforts to maintain its balance. Phrenologists, who attribute a different function to the Cerebellum, have attempted to put aside these results, on the ground that the severity of the operation was alone sufficient to produce them; but (as we have already seen, §. 465) after a much more severe operation,—the removal of the Cerebral Hemispheres, the Cerebellum being left untouched,—the animal could stand, walk, fly, maintain its balance, and recover it when disturbed.

482. The motions of the body in the Invertebrated classes, being simple in their nature, and probably all of a *reflex* character (§. 442) do not require a Cerebellum; and we do not find in them any nervous mass, which clearly represents this organ.

Functions of the Cerebrum.—Intelligence and Will.

483. From the facts already stated, it is tolerably clear that the Cerebrum is the organ by which we *reason* upon the ideas that are excited by sensations,—by which we judge and decide upon our course of action,—and by which we put that decision into practice, by issuing a mandate (as it were), which, being conveyed by the nervous trunks proceeding from the brain to the

muscles, excites the latter to contract. It is a common, but entirely erroneous idea, that *reason* is peculiar to Man; and that the actions of the lower classes of Animals are entirely due to Instinct. There can be no doubt, however, that reasoning processes exactly resembling those of Man, are performed by many of the Mammalia, such as the Dog, the Horse, and the Elephant; and it is probable that, although we are best acquainted with these animals, on account of their tendency to associate with Man, there are others which have powers yet higher. We must admit that an animal reasons, when it profits by experience, and obviously adapts its actions to the ends it desires to gain, especially when it departs from its natural instincts to do this. Such is continually the case with the animals just mentioned; and some striking examples of this will be mentioned hereafter (Chap. XIV). We perceive the presence of intelligence also, in the differences of character which we encounter among the various individuals of the same species; thus every one knows that there are stupid Dogs and clever Dogs, ill-tempered Dogs and good-tempered Dogs, as there are stupid Men and clever Men, ill-tempered Men and good-tempered Men. But no one could distinguish between a stupid Bee and a clever Bee, or between a good-tempered Wasp and an ill-tempered Wasp; simply because all the actions of *these* animals are prompted by an unvarying instinct.

484. Among Birds, too, there are many manifestations of Intelligence; which constitute a remarkable distinction between *their* actions, and those of Insects. The instinctive tendencies of the two classes bear a close correspondence with each other. Their mode of life is nearly the same, so that Birds may be called the Insects of the Vertebrated series, whilst Insects may be regarded as the Birds of the Articulated; and there are several curious points of analogy in the structure of their bodies. The usual arts which Birds exhibit in the construction of their habitations, in procuring their food, and in escaping from danger, must be regarded (like those of Insects) as *instinctive*; on account of the uniformity with which they are practised by different individuals of the same species, and the perfection with which

they are exercised on the very first occasion, independently of all experience. But in the adaptation of their operations to particular circumstances, Birds display a variety and fertility of resource, far surpassing that which is manifested by Insects,—as for instance, when they make trial of several means, and select that one which best answers the purpose; or when they make an obvious improvement from year to year in the comforts of their dwelling; or when they are influenced in the choice of a situation by peculiar circumstances, which, in a state of nature, can scarcely be supposed to affect them. All these are obvious indications of an Intelligence which Insects do not possess; that which is most wonderful in the actions of the latter (and there are none *more* wonderful) being the same in all the individuals of one species, being uninfluenced by education, and being performed under the immediate direction of an Intelligence much higher than the boasted reasoning power of Man.

485. Of the Mental operations to which the Cerebrum of Man is subservient, a general account will be given in a future Chapter. The present might seem to be the place for inquiring how far that doctrine is true, which assigns to different parts of the Cerebral hemispheres those different faculties and tendencies, in whose combined action the phenomena of Mind consist. That such a distribution may exist, the Author is far from thinking improbable; but as the doctrines of Phrenology, *in their present form*, are in his opinion far from being established, and as they appear to him inconsistent with many facts, which Comparative Anatomy and the observation of Disease, as well as the study of Human Character, supply, he prefers not entering here upon a discussion of them; particularly as they are easily to be learned from the publications of professed Phrenologists.

The next subject for consideration will be the structure and actions of the Organs of Sense, which may be regarded in the light of appendages to the Brain; being adapted to receive the various impressions, which are *there* to become the sensations of Touch, Taste, Smell, Hearing, and Sight.

CHAPTER XI.

ON SENSATION, AND THE ORGANS OF THE SENSES.

486. ALL beings of a truly Animal Nature possess, there is good reason to believe, a *consciousness* of their own existence, first derived from a *feeling* of some of the changes taking place within themselves; and also a greater or less amount of *sensibility* to the condition of external things. We have no sufficient ground for thinking that Plants possess any such endowments; for the motions which a few of them execute, and which form the only evidence of the presence of consciousness, may be explained in other ways; and the greater number of them, being entirely motionless, exhibit no such evidence. The consciousness which any Animal possesses, of that which is taking place within or around itself, is all derived from *impressions* made upon the extremities of certain of its nervous fibres; which, being conveyed by them to the central *sensorium*, are there *felt* (§. 432). Of the mode in which the impression, hitherto a change of a *material* character, is there made to act upon the *mind*, we are absolutely ignorant; we only know the fact. Hence, although we commonly refer our various sensations to the parts at which the impressions are made,—as for instance, when we say that we have a pain in the hand, or an ache in the leg,—we *really* use incorrect language; for, though we may refer our sensations to the points where the impression was made on the nerve, they are really *felt* in the brain. This is evident from two facts;—first, that if the nervous communication of the part with the brain be interrupted, no impressions, however violent, can make themselves felt; and second, that if the *trunk* of the nerve be irritated or pinched, anywhere in its course, the pain which is

felt is referred, not to the point injured, but to the surface to which these nerves are distributed. Hence the well-known fact that, for some time after the amputation of a limb, the patient feels pains which he refers to the fingers or toes that have been removed; this continues until the irritation of the cut extremities of the nervous trunks has subsided.

487. Among the lower tribes of Animals, it would seem probable that there exists no other kind of sensibility, than that which is termed *general* or *common*, and which exists, in a greater or less degree, in almost every part of the bodies of the higher. It is by this, that we feel those impressions, made upon our bodies by the objects around us, or by actions taking place within, which produce the various modifications of *pain*, the sense of *contact* or resistance, the sense of variations of *temperature*, and others of a similar character. From what was formerly stated, of the dependence of impressions made on the sensory nerves upon the action of the blood-vessels (§. 431), it is obvious that no parts destitute of the latter can receive such impressions, or (in common language) can possess sensibility. Accordingly we find that the hair, nails, teeth, tendons, ligaments, fibrous membranes, cartilages, and bones, whose substance either contains no vessels, or but very few, are either completely incapable of receiving painful impressions, or have but very dull sensibility to them. On the other hand, the skin, and other parts, which usually receive such impressions, are extremely vascular; and it is interesting to observe that some of the tissues just mentioned, when new vessels form in them in consequence of diseased action, become acutely sensible. It does not necessarily follow, however, that parts should be sensible in a degree proportional to the amount of blood they contain; since this blood may be sent to them for other purposes. Thus, it is a condition necessary to the action of Muscles, that they should be copiously supplied with blood (§. 593); but they are not acutely sensible; and Glands, also, the substance of which has very little sensibility, receive a large amount of blood for their peculiar purposes.

488. But besides the *general* or *common sensibility*, which is

diffused over the greater part of the body of most animals, there are certain parts which are endowed with the property of receiving impressions of a peculiar or *special* kind, such as sounds or odours, which would have no influence upon the rest; and the sensations which these excite, being of a kind very different from those already mentioned, arouse ideas in our minds, which we should never have formed without them. Thus, although we can gain a knowledge of the shape and position of objects by the touch, we could form no notion of their colour without sight, of their sounds without hearing, or of their odours without smell. The nerves which convey these *special* impressions are not able to receive those of a common kind: thus the Eye, however well fitted for seeing, would not feel the touch of the finger, if it were not supplied with branches from the 5th pair, as well as by the optic. Nor can the different nerves of special sensation be affected by impressions that are adapted to operate on others: thus the ear cannot distinguish the slightest difference between a luminous and a dark object; nor could the eye distinguish a sounding body from a silent one, except *by seeing* its vibrations. But Electricity possesses the remarkable power, when transmitted along the several nerves of special sense, of exciting the sensations peculiar to each; and thus, by proper management, this single agent may be made to produce flashes of light, distinct sounds, a phosphoric odour, a peculiar taste, and a pricking feeling, in the same individual at one time. The inference which might hence be drawn,—that Electricity and Nervous agency are identical,—is nevertheless premature, as will be shown hereafter (§. 587).

Sense of Touch.

489. By the sense of Touch is usually understood that modification of the *common sensibility* (§. 487) of the body, of which the surface of the skin is the especial seat. In some animals, as in Man, nearly the whole exterior of the body is endowed with it, in no inconsiderable degree; but in others, as in the greater number of Mammalia, most Birds and Reptiles, and many Fishes, the greater part of the body is so covered by

hairs, scales, or bony plates, as to be nearly insensible; and the faculty is restricted to particular portions of the surface, which often possess it in a very high degree. The sensory impressions, by which we receive the sensation of Touch, are made by the objects themselves upon the nerves which are distributed to the Skin; and into the structure of this tissue it is desirable that we should now enter, in more detail than formerly (§. 36).

490. The *Skin* is made up of two principal layers, the *Cutis vera* or true-skin, and the *Epidermis* or scarf-skin. The *Cutis vera* (sometimes also called the *Dermis*) is a firm and rather tough membrane, possessed of considerable elasticity, and having a very complex structure. It essentially consists of a vast number of fibres, interlacing with each other in every direction; of these fibres, some resemble those of the *white* and others those of the *yellow* elastic tissue; but the membrane thus formed is traversed by a vast number of blood-vessels, lymphatics, and nerves; and also by the ducts of the minute exhalant glands which lie beneath it (§. 371). The internal surface is in contact with a layer of cellular tissue, which intervenes between the skin and the muscles; this cellular tissue usually contains, also, a larger or smaller amount of fat-cells. The external surface of the true skin is not smooth, but is covered with an immense number of little elevations, or *papillæ* (§. 431), which in some parts of the body—as the palm of the hand, and the extremities of the fingers,—are arranged in regular rows. In each of these papillæ, there is a plexus or network of minute blood-vessels, surrounding the extremity of a filament of the sensory nerve, by which the skin is supplied; and the degree of sensibility of any part of the skin, bears a close correspondence to the number of papillæ, which are included within a given area of its surface.

491. The true skin or Dermis, from which alone leather is prepared, is thicker in most Mammalia than in Man; but the thickness of the skin does not by any means involve (as is commonly supposed) deficient sensibility. Thus in the Spermaceti Whale, it has been observed that the sensory nerves, which are destined to be distributed on the skin, pass through the blubber without giving off any considerable branches, but spread out into

a network of extreme minuteness, as soon as they arrive near the surface. It is a fact well known to Whale-fishers, especially to those who pursue this species, that these animals have the power of communicating with each other at great distances. It has often been observed, for instance, that, when a straggler is attacked, at the distance of several miles from a shoal, a number of its fellows bear down to its assistance, in an almost incredibly short space of time. It can scarcely be doubted that the communication is made through the medium of the vibrations of water, excited by the struggle of the animal, or perhaps by some peculiar movements specially designed for this purpose, and propagated through the liquid to the immense surface of the skin of the distant Whales.

492. The sensibility of the true skin would be too great, if it were not protected by the *Epidermis*, which is a layer of semi-transparent membrane, thin in some parts and thick in others, according as the part is to be endowed with acute sensibility, or protected from impressions of too strong a nature. Thus it is particularly thin at the ends of the fingers, and on the surface of the lips, which are used for *feeling;* but is thick on the palm of the hand, which is used for firmly *grasping,* and which would be continually suffering pain if its sensibility were too acute; and it is still thicker on the sole of the foot, especially on the heel and the ball of the great toe, where *pressure* is to be sustained. The Epidermis consists, as formerly stated (§. 35), of a vast number of minute cells, which are formed in layers upon the external surface of the true skin, or rather upon the *basement membrane* which covers it (§. 31). In Man, and most other soft-skinned animals, the outer layers of this Epidermis are continually being worn off; and new layers are as constantly being formed from within. Thus each layer is gradually pushed from within outwards; and its cells undergo a considerable change in their form, being nearly globular when first produced, and being gradually flattened into scales, by the loss of their contained fluid, as they approach the outer surface. It is in the latter condition, that they are pressed together into that continuous membrane, which is raised by the fluid poured out from the sur-

face of the true skin, where a blister has been applied or a hot body has touched it; when this has been removed, some more delicate layers are seen upon the surface of the true skin, which consist of cells having more of the globular form, and not holding firmly together. These soft layers were formerly regarded as constituting a distinct tissue, to which the name of *rete mucosum* (mucous network) was given; but this is now known to consist simply of the last-formed portions of the epidermis. It was supposed to be the peculiar seat of the colouring-matter of the skin; this does not form a distinct layer, however; but is contained in *pigment-cells* (§. 533) which lie among the ordinary cells of the epidermis, and are consequently diffused through its whole thickness.

493. In those animals in which the surface is covered with hard scales or plates, instead of with a soft epidermis, we not unfrequently find, that the layer is thrown off and renewed at intervals. This is the case, for instance, in Serpents, which annually cast their outer skin or *slough* (as it is commonly termed); and also in Crustacea, as well as many other Articulata. The cast skin or shell is commonly found to be very perfect, having only one small aperture through which the animal has managed to withdraw its body. In both Serpents and Crustacea, the transparent membrane covering the front of the eyes is thrown off with it; and in Crustacea we even find the lining membrane of the mouth and stomach ejected at the same time.

494. The Epidermis is continued over the sensory papillæ; but it is perforated by numerous apertures. Some of these are the perforations caused by the ducts of the sweat-glands; others give passage to the hairs; and others form the orifices of the sebaceous follicles by which the skin is in some parts abundantly beset (§. 375). It is only at the back of the fingers and toes, in Man, that the skin is covered with any protection harder than epidermis. The *nails* are formed upon the same plan with the epidermis, and may be considered as appendages of it; their principal function is to support the soft parts at the back of the point of the finger, and thus to enable the anterior surface to be better applied to the body that is to be touched or held by it.

495. Although the fingers of Man and the Quadrumana, being endowed with peculiar sensibility, are their special organs of *touch*, yet we find that they cease to be so in most of the other Mammalia (as in the lower Vertebrata), in which the extremities are adapted only for support and locomotion, and are terminated by hard claws or hoofs that completely envelop them. In most of these, we find the lips and tongue employed as the chief organs of touch; in the Elephant, this sense is evidently possessed very acutely by the little finger-like projection at the end of its trunk; and in the Bat, it seems to be diffused over the whole membrane of which the wings are formed. It has been found that Bats, when deprived of sight, and (as far as possible) of hearing and smelling also, still flew about with equal certainty and safety, avoiding every obstacle, passing through passages only just large enough to admit them, and flying through places previously unknown, with the most unerring accuracy, and without striking against the objects near which they passed. The same result happened, when threads were stretched in various directions across the apartment. Hence some Naturalists were inclined to attribute to the Bat the possession of a sixth sense unknown to Man; but Cuvier correctly pointed out that this idea becomes unnecessary, if we attribute to the delicate membrane of the wings (as we are justified in doing) a high degree of tactile sensibility, receiving its impressions from the pulses of the air, produced by the action of the wings, and modified by the neighbourhood of solid bodies.

496. The only idea communicated to our minds by the sense of Touch, when this is exercised in its simplest form, is that of *resistance;* and we cannot form a notion of the size or shape of an object, nor of the nature of its surface, by *feeling* it unless we *move* the object over our own sensory organ, or the latter over the former. By the various degrees of resistance which we encounter, we estimate the hardness or softness of the body; and by the impressions made upon the papillæ, when they are moved over its surface, we form our idea of its smoothness or roughness. It is by attention to the muscular movements we execute, in passing our hands or fingers over its surface, that we acquire our

ideas of its size and figure; and hence we perceive that the sense of touch, without the power of moving the tactile organ over the object, would have been of comparatively little use. This sense is capable of improvement to a remarkable degree; as we see in persons who have become more dependent upon it, in consequence of the loss of their sight. This doubtless results, in part, from the increased attention which is given to the sensations; and partly from the greater acuteness or impressibility of the organ itself, arising from the frequent use of it. Amongst other remarkable instances of this kind, was that of Saunderson, who, though he lost his sight at two years old, acquired such a reputation as a mathematician, that he obtained a Professorship at Cambridge. He exhibited, in several ways, an extraordinary acuteness in his touch; but one of his most remarkable faculties was the power of distinguishing genuine medals from imitations, which he could do more accurately than many connoisseurs in full possession of their senses.

497. The sense of *temperature* is of a different character from the common sensation of touch; and either may be lost, without the other being affected. It is rather of a *comparative* than of a *positive* kind; that is, we form our estimate of temperature rather by comparing it with that to which our body (or the part of it employed to test the heat or cold) has been previously exposed, than by the knowledge which we derive through the sensation, of the *actual* degree of heat or cold to which the organ is exposed. Thus, if we plunge one hand into a basin of hot water, and the other into cold, and then transfer both of them to a basin of tepid water, this will feel cold to the hand which has been previously accustomed to the heat, and warm to the other. In the same manner, the temperature of Quito, which is situated half way up a lofty mountain, is felt to be chilly by a person who has ascended from the burning plains at its base, whilst it seems intensely hot to another who has descended from its snow-capped summit; the residents in the town at the same time regarding it as moderate,—neither hot nor cold. It is a curious circumstance, that a weak impression made on a large surface, seems more powerful than a stronger impression made

on a small surface; thus, if the fore-finger of one hand be immersed in water at 104°, and the whole of the other hand be plunged in water at 102°, the cooler water will be thought the warmer; whence the well-known fact, that water in which a finger can be held, will scald the whole hand.

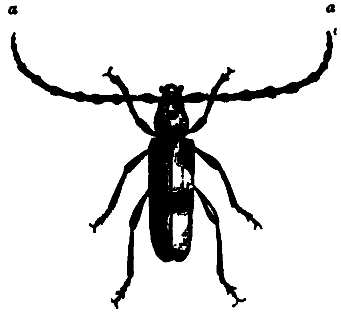

FIG. 187.—CAPRICORN-BEETLE.
a, a, antennæ.

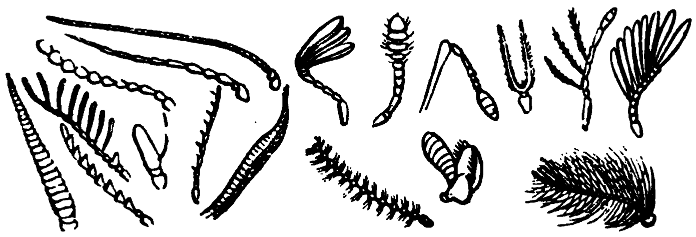

FIG. 188.—VARIOUSLY-FORMED ANTENNÆ OF INSECTS.

498. Where any special organs of Touch exist in Invertebrated Animals, they are for the most part prolongations from the portion of the head near the mouth. This is the case with the *arms* of the Cuttle-fish, and with the *tentacula* of the lower Mollusca, which are similar in position. Among Crustacea and Insects, the *antennæ* or feelers appear to be the special organs of touch. These are frequently very long, and present an extraordinary variety in their forms, of which some are depicted in the accompanying figure. They contain, for the most part, a large number of joints (in the Mole-Cricket above 100), and are very flexible. This flexibility enables them to be turned towards any object which the Insect wishes to examine; and when the animal is walking, we see them constantly being applied to the surfaces of the bodies which it approaches, in a manner which leaves little doubt that they

are used as organs of touch. It is no objection to this view, to say that their surfaces are hard, and consequently that no delicate sensations can be received through them; for the slightest contact of their firmest points with a hard substance, may produce a sense of resistance, which will afford to the animal the information which it requires. The stick used by the blind man in feeling his way, serves a very similar purpose.

499. It appears to be by sensations received through their antennæ, that Bees and other Insects, which naturally work in the dark, are enabled to carry on their labours without confusion or inaccuracy; and by the same means, that they communicate with each other. When the antennæ are cut off, the Bee at once ceases to work, and seems unable to direct its movements in any other way than towards the light. When any important event has happened in a community, such as the loss of the Queen, the spreading of the intelligence through the whole hive may be watched by a close observer. The working bees which were near her are observed to run about restlessly, applying their antennæ to those of the others they may meet, crossing them and striking lightly with them; these in their turn become agitated and do the same; and thus the intelligence is speedily propagated through the whole hive. In the same manner, when two bees meet each other out of their hives, they seem to reconnoitre one another for some time, by the movements of their antennæ; and often keep up these movements for a considerable period, as if carrying on a close conversation. That the antennæ are delicate organs of touch can, therefore, be scarcely questioned.

Sense of Taste.

500. The sense of taste, like that of touch, is excited by the direct contact of particular substances with certain parts of the body; but it is of a much more refined nature than touch, inasmuch as it communicates to us a knowledge of properties which that sense would not reveal to us. All substances, however, do not make an impression on the organ of taste. Some of them have a strong savour, others a slight one, and others again are altogether insipid. The cause of these differences is not

understood; but it may be remarked that, in general, bodies which cannot be dissolved in water, have no savour; whilst most of those which are soluble, have a more or less strong taste. Their solubility, in fact, seems to be one of the conditions requisite for their action on the organ of taste; for when that organ is completely dry, it does not receive any sensation from solid bodies brought into contact with it, which may have the most powerful taste if reduced to a fluid form; and there are substances known, which, being perfectly insoluble in water, are insipid if applied to the tongue, when it is covered as usual with a watery secretion; but which have a strong taste, when they are dissolved in some other liquid, spirit of wine for instance.

501. The sense of Taste has for its chief purpose, to direct animals in their choice of food; hence its organ is always placed at the entrance to the digestive canal. In higher animals, the tongue is the principal seat of it; but other parts of the mouth are also capable of receiving the impressions of certain savours. The mucous membrane which covers the tongue, is copiously supplied with blood-vessels; and is thickly set, especially upon its upper surface, and towards the tip, with *papillæ*, resembling in structure those of the skin, but larger (§. 490). The tongue itself is made up of muscular substance, which accomplishes the varied movements, that are required in the acts of mastication, and in the production of articulate sounds. It is supplied with nerves from the third division of the fifth pair, from the glosso-pharyngeal, and from the hypoglossal (§. 458). The last is the motor nerve of the tongue; the first is the one chiefly concerned in the conveyance of sensory impressions from the front and sides of the tongue; and the other (the glosso-pharyngeal) seems to have for its office, the conveyance of those impressions from the back of the tongue, which excite the muscles of swallowing to action (§. 476), as well as those which produce the sensation of nausea, and excite the act of vomiting. The papillæ are, for the most part if not entirely, supplied from the fifth pair; and the branch of this, proceeding to the tongue, is known as the *lingual* nerve. When they are called into action by the contact of substances having a pleasant savour, they not unfrequently

become very turgid, and rise up from the surface of the mucous membrane; in this manner is produced the roughness, that is felt on the surface of any portion of the tongue or inside of the cheek, against which a piece of barley-sugar, or other similar substance, has lain for some little time.

501. A considerable part of the impression produced by many substances, is received through the sense of smell, rather than by that of taste. Of this any one may convince himself, by closing the nostrils, and breathing through the mouth only, whilst holding in the mouth, or even rubbing between the tongue and the palate, some aromatic substance; its taste is then scarcely recognised, although it is immediately perceived when the nasal passages are re-opened, and its effluvia are drawn into them. There are many substances, however, which have no aromatic or volatile character; and whose taste, though not in the least dependent upon the action of the nose, is nevertheless of a powerful character; but these for the most part produce, by irritating the mucous membrane, a sense of pungency, allied to that which the same substances (acids, for instance, pepper, or mustard,) will produce, when applied to the skin for a sufficient length of time. Such sensations, therefore, are evidently of the same *kind* with those of Touch; differing from them only in the *degree* of sensibility of the organ through which they are received. The sense of Taste, then, in its ordinary acceptation, may be regarded as a compound of those of Smell and Touch.

502. This sense has a very important function in most animals which possess it,—that of directing them in their choice of food. Most of the lower animals will instinctively reject articles of food, that would be pernicious to them; thus even the voracious Monkey will seldom touch fruits of a poisonous character, though their taste may be agreeable; and animals whose digestive apparatus is adapted to one kind of food, will reject all others. As a general rule it may be stated, that substances of which the taste is agreeable to us, are useful and wholesome articles of food; and *vice versâ:* but there are many signal exceptions to this. It is interesting to remark that in Man, when the reasoning powers are obscured by disease, his instincts in regard to food often

manifest themselves strongly, and constitute the best guide in its administration; thus, there are many cases of fever, in which the physician is in doubt whether wine will be injurious or beneficial; and he will usually find the disposition of the patient to reject it, or his readiness to receive it, to be his best guide. And in general it may be remarked that, in illness, the desire of the patient for food, or his indisposition to take it, pretty certainly indicate the fitness or unfitness of the system to digest and appropriate it.

503. The tongue presents nearly the same structure among the Mammalia in general, as in Man; but in Birds it is usually cartilaginous or horny in its texture, and destitute of nervous papillæ, so that the sense of taste cannot be very acute in any of these animals. Several of them use their tongues for other purposes,—the Woodpecker, for instance, to transfix insects, and the Parrots to keep steady the nut or seed, which is being crushed between the jaws. In some Reptiles the tongue is large and fleshy; in others long and slender; in others, again, it is almost entirely deficient: but in no instance does it seem to minister to any acute sense of taste. In Fishes it is for the most part absent. Many Invertebrated animals possess a tongue; but its uses are for the most part mechanical. Thus the tongue of the Limpet is a powerful rasp, by which it rubs down the sea-weeds on which it feeds; whilst the tongue of the Bee forms a channel through which it draws up the juices of flowers. In most Insects, the *palpi*, small jointed appendages in the neighbourhood of the mouth (§. 172) seem to answer the purpose of an organ of taste; being observed to be in incessant motion, whilst the animal is taking food, touching and examining it before it is introduced into the mouth.

Sense of Smell.

504. Certain bodies possess the property of exciting in us sensations of a peculiar nature, which cannot be perceived by the organs of taste or touch, and which seem to depend upon emanations that are spread from them through the air, producing what we term *odours*. It seems probable that odours are, in

reality, very finely-divided particles of the odoriferous substance; and this idea derives support from the fact, that most volatile bodies are more or less odorous; whilst those which do not readily transform themselves into vapour, have little or no fragrancy in their natural state, but possess strong odorous properties as soon as they are converted into vapour—by the aid of heat, for instance. The most powerful and penetrating odours are for the most part those of bodies already in a gaseous state,—such as sulphuretted and carburetted hydrogen; or of fluids which readily pass into the state of vapour, as the vegetable essential oils. But there are some solid substances, as musk, which are very strongly odoriferous; and which do not appear to diffuse themselves in the air, in the state of vapour. The odorous particles of these must be of extreme minuteness; for the substances do not seem to lose weight, by freely imparting their peculiar scent to an unlimited quantity of air. Thus the experiment has been tried, of keeping a grain of musk freely exposed to the air of a room of which the doors and windows were constantly open, for a period of ten years; the air, thus continually changed, was completely impregnated with the odour of musk; and yet at the end of that time, the particle was not found to have suffered any perceptible diminution in weight.

505. In order that we should become sensible of odours, it seems necessary that the odoriferous particles should come into actual contact with the membrane, on which the nerve of smell is spread out. In this respect, the sense of Smell agrees with those of taste and touch; whilst it differs from those of sight and hearing, which take cognisance of changes that are produced by vibrations or undulations in the surrounding medium. It is, moreover, desirable that these odorous particles should be conveyed by the air, and not be diffused through fluid; for though it is necessary to the perfection of the sense of smell, that the olfactory membrane should be kept moist, too great a quantity of fluid upon its surface deadens its peculiar sensibility,—as we find to be the case, when we are suffering under an ordinary cold. Hence it is only in air-breathing animals, that the sense of Smell can possess any considerable acuteness.

506. The most advantageous position of this organ is evidently at the commencement of the respiratory passages; so that the air, which is being received into the lungs, may pass through it, and be *tested*, as it were, by its peculiar sensibility. In all the air-breathing Vertebrata we find a pair of cavities, the *nasal fossæ*, which are situated between the mouth and the orbits. They possess two orifices,—the *anterior nares*, or *nostrils*, usually opening upon the front of the face,—and the *posterior nares*, which open into the pharynx. The two cavities are separated from each other by a vertical partition, which passes backwards and forwards on the middle line; their sides are formed by the various bones of the face, and by the cartilages of the nose; their extent is very considerable, especially in animals that have a prolonged muzzle. The interior of these cavities is lined by a delicate mucous membrane, on which the olfactory nerves are distributed; and the extent of this is increased, by its being folded over certain projections from the walls of the cavity, which are termed *spongy bones*. Of these there are three in Man. Prolongations of this membrane are carried also into cavities hollowed out in the neighbouring bones, which are termed *sinuses*. Thus we have the frontal sinuses, *l*, situated just above the nose, between the eyebrows; and the sphenoidal sinuses, *m*, situated further back. There is also a large cavity hollowed out in the bone of the upper jaw on either side. The membrane which lines these is kept moist by its own secretion; and it is covered with vibratile *cilia*, the office of which seems to be, to prevent that secretion from unduly accumulating, by conveying it over the surface of the membrane to the outlet.

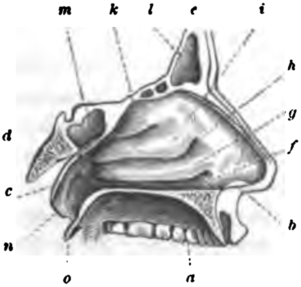

FIG. 189.—VERTICAL SECTION OF THE NASAL CAVITY.

a, mouth; *b*, nostril; *c*, posterior opening; *d*, portion of the base of the skull; *e*, forehead; *f*, *h*, passages between the spongy bones, *g*, *i*, *k*; *l*, frontal sinus; *m*, sphenoidal sinus; *n*, opening of Eustachian tube; *o*, curtain of the palate.

507. The mechanism of the sense of Smell is very simple;

when air charged with odorous particles passes over the membrane that lines the nose, some of these particles are delayed by the mucous secretion that covers it, and act upon the delicate sensory extremities of the olfactory nerve, with which it is thickly set. The highest part of the nasal cavity appears to be that, in which there is the most acute sensibility to odours; and hence it is that, when we *snuff* the air, so as to direct it into the upper part of the nose, instead of allowing it to pass simply along the lower portion from the anterior to the posterior nares, we perceive delicate odours which would have otherwise escaped us.—The acuteness of the sense of smell depends, in no small degree, upon the extent of surface exposed by the membrane lining the nasal cavity, and in this respect Man is far surpassed by many of the lower Mammalia, especially among the Carnivora, Ruminantia, and some Pachydermata. The extreme delicacy of this sense in the Deer, Antelopes, &c. is well known, from its being a source of great difficulty to the hunter, who cannot advance near enough to attack them, except by stealing upon them in the direction contrary to that of the wind. In these animals it serves as the chief means by which they are warned of the proximity of their enemies; in the Carnivora, on the other hand, it serves to direct them to their prey. In general, however, it seems to have for its office to assist in directing animals to their food, and in warning them of the presence of noxious vapours.

508. Besides receiving the olfactory nerve, the mucous membrane of the nose receives branches of the fifth pair; this nerve endows it with *common* sensibility, and also receives the impressions produced by acrid or pungent vapours, which act upon it in the same way as the corresponding fluids do upon the tongue. Such vapours are *felt* by the irritation they produce, rather than *smelt;* and the impression they occasion, gives rise to the reflex action of *sneezing*, by which they are driven from the nose (§. 372). Hence this action will be excited by an irritating cause (such as snuff), after the olfactory nerve has been divided, if the branches of the fifth pair be entire; whilst it does not take place when the fifth pair is paralysed, even though the sense of smell may be retained. This sense loses much of its

acuteness, however, when the branches of the fifth pair supplying this organ can no longer discharge their functions; for the membrane then becomes dry, from the want of its proper secretion; and the odorous particles are consequently not properly applied to it.

509. Among animals that live in water, the olfactory organs cannot act to much advantage; and we do not find much provision made for this sense. In the Whale tribe, the nostrils serve as the channel by which the water is expelled that has been drawn in through the mouth (§. 184); they are situated at the top of the head, and are known as *blow-holes*. In Fishes, the nasal cavity has no posterior opening; but the surface of its lining membrane is very much extended by its arrangement in folds, which are sometimes disposed in a radiated manner, around a centre, and sometimes parallel, like the teeth of a comb. There are many Invertebrated Animals, from whose actions it may be judged that they possess a delicate sense of smell; although the precise seat of it cannot be assigned. This is the case especially with Insects, Crustacea, and the higher Mollusca. The lining membrane of the air-tubes of Insects appears to be delicately sensitive to irritating vapours (§. 443); but we have no evidence that it ministers to the sense of Smell properly so called.

Sense of Hearing.

510. By this sense we become acquainted with the sounds produced by bodies, in a certain state of vibration. The vibrations which the sounding bodies undergo, are communicated by them to the air, producing in it a series of undulations or waves, by which the sound is conveyed to a great distance. These undulations spread more widely as they become more distant from the sounding body, just like the ripples produced on the surface of water when we throw a stone into it; and in proportion as they spread, they become less powerful. This is the reason why Sound becomes less intense, as the sounding body is more distant. Although air is the usual conducting medium for the sonorous undulations, liquids or solids may answer the same purpose. Thus, if a person hold his head under water, whilst two stones

are struck together, also under water, at a considerable distance, he will hear the sound produced by the blow, with extreme distinctness, and even with painful force. Or if the ear be laid against one end of a long piece of timber, whilst a scratch with a pin be made on the other, or a watch be laid upon it, even the faint sounds produced by these will be heard very distinctly. That a medium of some kind is necessary to convey the sonorous vibrations, is proved by the fact, that, if a bell be made to ring in the receiver of an air-pump from which the air has been exhausted, no sound is heard, though its ringing immediately becomes audible when the air is allowed to re-enter.*

511. It is a fact of much importance, in regard to the action of the organ of Hearing, that sonorous vibrations which have been excited, and are being transmitted, in a medium of one kind, are not imparted with the same readiness to others. The following conclusions have been drawn from experimental inquiries on this subject. I. Vibrations excited in solid bodies may be transmitted to water without much loss of their intensity; although not with the same readiness that they would be communicated to another solid. II. On the other hand, vibrations excited in water lose something of their intensity in being propagated to solids; but they are returned, as it were, by these solids to the liquid, so that the sound is more loudly heard in the neighbourhood of those bodies than it would otherwise have been. III. The sonorous vibrations of solid bodies are much more weakened by transmission to air; and those of air make but little impression on solids. IV. Lastly, sonorous vibrations in water are transmitted but feebly to air; and those which are taking place in air are with difficulty communicated to water; but the communication is rendered much more easy, by the intervention of a membrane extended between them.

512. The *Auditory* nerve, or nerve of Hearing, is adapted to receive and transmit to the brain, the sonorous undulations produced in the surrounding medium by vibrating bodies. Now it is obvious that it may be affected by these in various ways, especially in animals that inhabit the water. The vibrations excited

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* See Treatise on ACOUSTICS.

in the liquid will be transmitted to the solid parts of the head, and thence to the nerve contained in it, without much interruption ;—and this independently of any special apparatus of hearing. Indeed, the simplest form of this apparatus is only designed, to give increased effect to the vibrations thus excited in the solid parts of the head; for it consists merely of a cavity excavated in their thickness, which cavity is filled with fluid, and is lined by a membrane on which the auditory nerve is minutely distributed. This is the form of the organ of hearing in the Mollusca, where any such exists; and also in many of the Crustacea. In those of the latter class which chiefly inhabit air, however, this cavity is excavated in the surface of the shell covering the head; and is shut in by a membrane, which is exposed to the surrounding medium. According to the principle (IV.) mentioned in the last paragraph, the liquid contained in the chamber will be thrown into undulation by vibrations in air, as well as by those of water; so that those animals which possess this kind of apparatus, are able to hear much better in air than those in which the cavity is completely shut in by stony walls. Of the degree in which sonorous vibrations may be communicated to our own auditory nerves through the solid parts of the skull, we may easily satisfy ourselves by closing the ears carefully, and placing any part of the head against a solid body which communicates with the one in vibration. In this manner we may hear the sounds produced by the latter with considerable distinctness, though accompanied by an unpleasant *jarring*. A deaf gentleman was once agreeably surprised to find that, when smoking his pipe, with the bowl resting on his daughter's piano-forte, he could distinctly hear the music she was producing from it; and many deaf persons may be made to hear conversation, by holding a piece of stick between their own teeth and placing it against the teeth of the person speaking.

513. In animals which have the organ of hearing constructed upon the simple plan just described, the force of the vibrations of the fluid contained in the cavity is increased by several minute stony concretions suspended in it; these act according to the second principle just stated (§. 511). They are termed *otolithes*,

or ear-stones; and some traces of them may be found even in Man and the higher animals.

514. We see, then, that a cavity excavated in the solid walls of the head, covered in externally by a membrane, having the auditory nerve distributed upon its walls, and filled with fluid, —is the simplest form of the organ of hearing; and may be regarded as including all that is *essential* to the exercise of this function. No more complicated apparatus is to be found in any of the Invertebrata; and even in the lowest Fishes, there is but little variation from this type. On the other hand, in Man and the higher Vertebrata, we find a very complex structure, adapted to render the faculty much more perfect; by receiving impressions, which make us aware, not only of the presence of a sounding body, but of its nature, its direction, the pitch and peculiar quality of the sound; and also, it is probable, by taking cognizance of sounds much fainter than those, which would be perceptible to the lower animals. Yet even in the most complicated forms of the organ of hearing, we shall find that the *essential* part is still the same, as that which forms the whole organ in the lower tribes; and that the faculty is still possessed, though in an inferior degree, when by disease or injury the *accessory* parts are prevented from acting. To the structure of the Ear of Man we shall now proceed.

515. The organ of hearing in Man may be divided into three parts,—the *external*, *middle*, and *internal* ear. The former is the fibro-cartilaginous appendage, placed on the outside of the head, to receive and collect the sounds which are to be transmitted to the interior; the two latter divisions are excavated in a bone of remarkable solidity,—the petrous (stony) portion of the temporal bone. The uses of the different hollows and elevations on the surface of the external ear of Man, are not very apparent; but it is probable that they direct the sonorous undulations towards the entrance of the canal which leads to the middle ear. The form of the external ear in many Quadrupeds evidently adapts it to this purpose; and there are several which have the power of changing its direction by muscular action, in such a manner as to enable it to

catch most advantageously the faintest sounds from any quarter. This is especially the case with animals that are naturally timorous, such as the Hare or the Deer; these have usually very large external ears. But it is among the Bat tribe,—whose residence in the dark recesses of caverns and excavations makes their eyes of comparatively little use to them, and causes them to depend greatly for guidance in their movements upon the sense of hearing,—that we find the greatest development of the external ear.

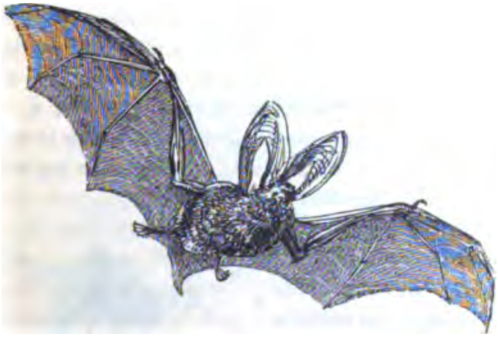

FIG. 190.—LONG-EARED BAT.

516. The canal (*d*, Fig. 193), into which the external ear collects the sonorous vibrations, passes inwards, until it is terminated by a membrane stretched across it, which is called the *membrana tympani*, or membrane of the *drum* of the ear (*g*). This forms the outside wall of a cavity excavated in the petrous portion of the temporal bone, the inner wall of which is bony, and forms the partition between the *middle* and *internal* ear. The cavity of the tympanum, constituting the middle ear, is not one of the *essential* parts of the organ; for nothing analogous to it exists in Fishes, nor in the lower Reptiles. It contains air; and communicates with the back of the nasal cavity (*n*, Fig. 189) by a canal termed the Eustachian tube (*k*, Fig. 193). It is the partial or complete closure of this tube, by swelling of its lining membrane, or by the viscid secretion from it, that occasions the slight deafness common among those who are suffering from

colds. Within the cavity of the tympanum, there is a very curious apparatus of small bones and muscles, which serves to establish a connection between the membrane of the drum, and the small membrane covering the entrance to the internal ear. These bones are four in number; and are termed the *malleus* or hammer (*a*, Fig. 191); the *incus*, or anvil (*b*); the *os orbiculare*, a minute globular bone (*c*); and the *stapes*, or stirrup-bone (*d*). These bones are connected together in the manner represented in Fig. 192; where *a a* represents the wall of the tympanic cavity; *b*, the membrana tympani; *c*, one of the long processes of the malleus, which is attached to the membrane; *d*, the head of the malleus, which articulates with the incus; *e*, the other long process of the malleus, which is acted on by the minute muscle, *f*; *g*, the incus, of which one leg is in contact with the wall of the cavity, whilst the other is connected with the orbicular bone, *h*; *i*, the stapes, of which the upper end is connected with the orbicular bone, whilst the lower (which is of an oval form) is attached to the membrane that covers the entrance to the internal ear; and *k* is a small muscle which acts upon this bone, in such a manner as to regulate its movements.

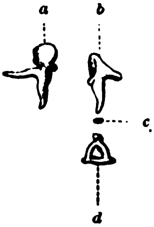

FIG. 191.
BONES OF THE EAR.

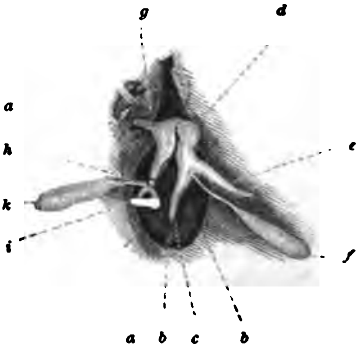

FIG. 192.—CAVITY OF THE TYMPANUM, WITH THE BONES IN THEIR PLACES.

517. The use of this apparatus is evidently to receive the sonorous vibrations from the air, and to transmit them to the membrane forming the entrance to the internal or essential part of the organ of hearing; in such a manner, that the sonorous vibrations excited in the latter may be much more powerful than they would be if the air acted immediately upon it. The usual state of the membrane of the tympanum appears to be rather lax

or slack ; and when in this condition, it vibrates in accordance with grave or deep tones. By the action of a small muscle lodged within the Eustachian tube, it may be tightened, so as to vibrate in accordance with sharper or higher tones; but it will then be less able to receive the impressions of deeper sounds. This state we may artificially produce, by holding the breath and forcing air into the Eustachian tube, so as to make the membrane bulge out by pressure from within ; or by exhausting the cavity, by an effort at inspiration with the mouth and nostrils closed, which will cause the membrane to be pressed inwards by the external air. In either case the hearing is immediately found

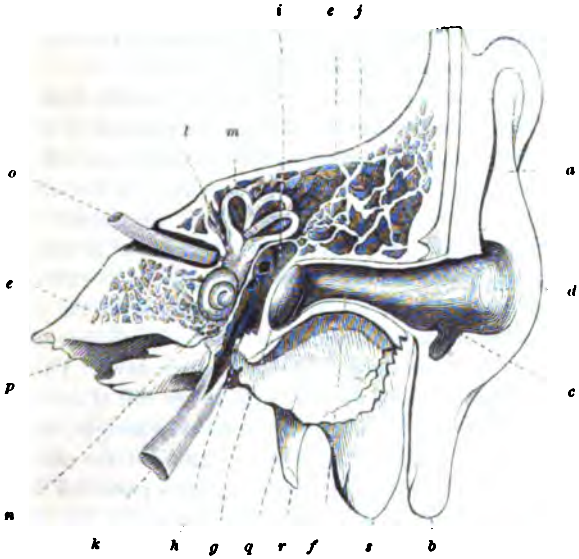

FIG. 193.—VERTICAL SECTION OF THE ORGAN OF HEARING IN MAN.

The internal portions are enlarged to make them more evident. *a*, *b*, *c*, the external ear; *d*, entrance to the auditory canal, *f*; *e*, *e*, petrous portion of the temporal bone in which the internal ear is excavated; *g*, membrane of the tympanum; *h*, cavity of the tympanum, the chain of bones being removed; *i*, openings from the cavity into the cells, *j*, excavated in the bone; on the side opposite the membrana tympani are seen the fenestra ovalis and rotunda; *k*, Eustachian tube; *l*, vestibule; *m*, semicircular canals; *n*, cochlea; *o*, auditory nerve; *p*, canal by which the carotid artery enters the skull; *q*, part of the glenoid fossa, which receives the head of the lower jaw; *r*, styloid process of the temporal bone.

to be indistinct; but it will be observed that the experimenter thus renders himself deaf to grave sounds, whilst acute sounds are heard even more distinctly than before. There is a different limit to the acuteness of the sounds, of which the ear can naturally take cognizance, in different persons. If the sound be so acute (or high in pitch) that the membrana tympani will not vibrate in unison with it, the individual will not hear it, although it may be loud; and it has been noticed that some persons cannot hear the very shrill tones produced by particular Insects, or even by Birds, which are distinctly audible to others.

518. The *internal ear* is composed of various cavities that communicate with each other; of these the *vestibule* (*l*, Fig. 193) may be regarded as the centre; from it there pass off, on one side, the *three semicircular canals*, *m;* and, on the other, the *cochlea*, *n*. The *vestibule* is the part which corresponds with the simple cavity, that constitutes the whole organ of hearing in the lower animals; and the others may be regarded as extensions of it for particular purposes. It communicates with the cavity of the tympanum, by a small orifice in the bony wall that separates them, termed the *fenestra ovalis*, or oval window. This orifice is closed by a membrane, to which the lower end of the stapes is attached. The *three semicircular canals* are passages, excavated in the solid bone, and lined by a continuation of the same membrane as that which lines the vestibule; each passes off from the vestibule and returns to it again. The *cochlea* (*n*, Fig. 193), or snail-shell, also is a cavity excavated in the hard bone, and lined by a continuation of the same membrane; its form is almost precisely that of the interior of a snail-shell (whence its name), being a spiral canal which makes about two turns and a-half round a central pillar. This canal is divided into two, however, by a partition that runs along its whole length; which partition is partly formed by a very thin lamina of bone, and partly (in the living state) by a delicate membrane. The two passages do not communicate with each other except at the top or centre; at their lower end (corresponding to the *mouth* of the snail-shell) they terminate differently; for whilst one freely opens into the vestibule, the other communicates with the cavity of the tympa-

num, by an aperture termed the *fenestra rotunda* (round window), which is closed by a membrane.* Thus the internal ear communicates with the cavity of the tympanum, by two minute orifices only,—the *fenestra ovalis*, and the *fenestra rotunda*, both of them closed by membranes, against the former of which the *stapes* abuts, whilst the latter is free.

519. The whole internal ear is lined by a delicate membrane, on which the auditory nerve (*o*, Fig. 193) is very minutely distributed; and its termination in *papillæ* is particularly well seen on the partition between the two passages of the cochlea. The cavities are completely filled with fluid, which is set in vibration by the movements of the stapes, communicated through the membrane of the *fenestra ovalis;* and these vibrations are probably rendered more free, by the existence of the second aperture—the *fenestra rotunda.* It is by the influence of these undulations upon the expanded fibrils of the auditory nerve, that the sensation of sound is produced; but in what way the different parts of the *labyrinth* (as this complex series of cavities is not unaptly called) contribute to the performance of this function, is not yet known. In all but the lowest Fishes, the three semicircular canals exist; but there is no vestige of a cochlea. In the true Reptiles, a rudiment of the cochlea may be generally discovered. In Birds, this cavity is more completely formed, though the passage is not spiral, but is nearly straight; of its real character, however, there can be no doubt, from its being divided, like the cochlea of Man, by a membranous partition on which the nerve is spread out.

520. In almost every instance in which the *semicircular canals* exist at all, they are three in number, and lie in three different directions, corresponding to those of the bottom and two adjoining sides of a cube; hence it has been supposed, and with much probability, that they assist in producing the idea of the *direction* of sounds. It has been also supposed, that the *cochlea* is the organ by which we judge of the *pitch* of sounds, and this would seem to be not improbable, especially when we compare

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* A double spiral staircase, constructed exactly on this plan, has recently been described as existing in Tamworth church.

the development of the cochlea, in different animals, with the variety in the pitch of the sounds which it is important that they should hear distinctly, especially the voices of their own kind. The *compass* of the voice (that is, the distance between its highest and lowest tones) is much greater in Mammalia than in Birds; as is also the length of the cochlea. In Reptiles, which have little true vocal power, the cochlea is reduced to its lowest form; and in the Amphibia, it disappears altogether.

521. That the Vestibule, and the passages proceeding from it, constitute even in Man the essential part of the organ of hearing, is evident from the fact, that when (as happens not unfrequently) the membrana tympani has been destroyed by disease, and the chain of bones has been lost, the faculty is not by any means abolished, though it is deadened. In this state, the vibrations of the air must act at once upon the membrane of the fenestra ovalis, as in the lower animals which possess no external or middle ear; instead of striking the membrane of the tympanum, and being transmitted along the chain of bones.

522. It has been stated (§. 510) that the sensation of hearing is produced by the successive undulations or vibrations communicated to the Ear, from the sounding body, by the air, or by a liquid or solid medium. This is the case with all *continued* sounds or *tones;* but single momentary sounds, such as those produced by the discharge of a pistol, the blow of a hammer, the ticking of a watch, or the beat of a clock, make their impression on the ear by a single shock. All continuous tones are in fact caused by a succession of such shocks, communicated to the ear with sufficient rapidity for the interval between them not to be distinguished. Thus, if we cause a tight string to vibrate, by pulling or striking it, we occasion—not one vibration only—but a long succession (MECHAN. PHILOS. §. 187), every one of which gives a new impulse to the air, and produces a new impression on the organ of hearing. These vibrations we can *see*, when they are sufficiently extensive; and we can always *feel* them, by placing the finger on the string. In the same manner, the vibrations of a bell or of a tuning-fork continue long after the first blow; and these, though we cannot see them, may be

readily felt with the finger. It is, in fact, in their power of continuing to vibrate after they have been struck, that the peculiarity of these resonant bodies consists. In other instances in which continuous tones are produced, the vibrations are kept up by the continued application of the original cause, and cease as soon as it is withdrawn; this is the case, for instance, in the string of the violin when set in vibration by the bow, and in the flute and organ-pipe when caused to sound by the passage of air through them.

523. In all these cases, then, the continued tones are due to a succession of impulses given by the sounding body to the air; and according to the *rapidity* with which the impulses succeed one another, will be the *pitch* of the sound. It is not difficult to ascertain by experiment the number of such impulses required to produce particular tones. Thus, if a spring be fixed near the edge of a revolving toothed wheel, in such a manner as to be caught by every tooth as it passes, a succession of *clicks* will be heard; and, if the revolution be sufficiently rapid, these will produce a tone. The number of teeth which pass the spring in a given time, being known by the rate of the revolution of the wheel, and by the number of teeth upon its circumference, we are enabled to ascertain the number of impulses, which are required to produce any given tone. The lowest note (C) given by any musical instrument (that which is produced by an open organ-pipe of 32 feet long, or by a stopped pipe of 16 feet) requires 16 impulses per second;* but continuous tones have been produced by impulses occurring at the rate of only 7 or 8 per second; so that the impression produced upon the ear by each, must have lasted at least 1-7th or 1-8th of a second. On the other hand it has been ascertained that the ear can appreciate tones produced by 24,000 impulses in a second; so that the limit already adverted to (§. 517) must be above this tone, the pitch of which is about 4 octaves above the highest F of the piano forte.

524. The *strength* or *loudness* of musical tones depends

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* A backward as well as forward vibration must take place with every impulse; consequently the number of the *vibrations* is *twice* that of the *impulses*.

upon the force and extent of the vibrations communicated by the sounding body to the air. Thus, when we draw the middle of a tight string far out of the straight line, and then let it go, a loud sound is produced, and we can *see* that the space through which the string passes from side to side is considerable. As the extent of the vibrations of the string diminishes, the sound becomes less powerful; and when we can no longer see the vibrations, but can only *feel* them, the sound is faint. The length of the undulations in the air corresponds with that of the vibrations in the sounding body; and consequently they will strike upon the tympanum with more or less force, as these are longer or shorter. The cause of the differences in the *timbre* or quality of musical tones,—such, for instance, as those which exist between the tones of a flute, a violin, and a trumpet, all sounding a note of the same pitch,—are unknown; but they probably depend upon the different *form* of the vibrations.

525. The faculty of hearing, like that of sight, may be very much increased in acuteness by cultivation; but this increase depends rather upon the habit of attention to the faintest impressions made upon the organ, than upon any change in the organ itself. This habit may be cultivated in regard to sounds of some one particular class; all others being heard as by an ordinary person. Thus, the watchful North American Indian recognises footsteps, and can even distinguish between the tread of friends or foes, whilst his companion, who lives among the busy hum of cities, is unconscious of the slightest sound. Yet the latter may be a Musician, capable of distinguishing the tones of all the different instruments in a large orchestra, of following any one of them through the part which it performs, and of detecting the least discord in the blended effects of the whole,—effects, which would be to his coloured friend but an indistinct mass of sound. In the same manner, a person who has lived much in the country is able to distinguish the note of every species of bird which lends its voice to the general concert of Nature; whilst the inhabitant of a town hears only a confused assemblage of shrill sounds, which may impart to him a disagreeable rather than a pleasurable sensation.—Of the *direction*

and *distance* of sounds, our ideas are for the most part formed by habit. Of the former we probably judge in great degree, by the relative intensity of the impressions received by the two ears; though we may form some notion of it by a single organ (§. 520). Of the distance we judge by the intensity of the sound, comparing it with that which we know the same body to produce when nearer to us. The Ear may be deceived in this respect as well as the eye (§. 566); thus the effect of a full band at a distance may be given by the subdued tones of a concealed orchestra close to us; and the Ventriloquist produces his deceptions, by imitating, as closely as possible, not the sounds themselves, but the manner in which they would strike our ears.

Sense of Sight.

526. By the faculty of Sight we are made acquainted, in the first place, with the presence of *light;* and by the medium of that agent, we take cognizance of the form of surrounding bodies, their colour, size, and position. As to the nature of Light itself, philosophers are at present divided; some believing that it is propagated by rays, consisting of actual particles emitted from the luminous body; while others consider it more probable, that it is transmitted by means of vibrations or undulations, analogous to those by which sound is propagated (§. 510). The latter theory renders it necessary to suppose that all space is filled with a very *rare** medium (to which the name of *luminous ether* has been given), that serves for the transmission of these undulations; and this idea derives support from facts, which the science of Astronomy reveals to us. (See ASTRONOMY, §. 539 and 642). Practically speaking, however, it is of little consequence which doctrine is true; since we are alone concerned respecting the laws that regulate the transmission of the rays of light, which are the same under both theories. Of these laws, it is desirable that a short account should be here given; since, without the knowledge of them, the beautiful action of the Eye cannot be understood.

527. The rays of light uniformly travel in straight lines, as long as they traverse the same medium (air, water, or glass, for

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* The opposite of *dense*.

instance), without obstruction. In passing from a single luminous point into space, they diverge or separate, in such a manner as to cover a larger and larger surface as they advance; and at the same time the intensity of the light is diminished. (See MECHAN. PHILOS. §. 91). But when the rays pass from one medium to another more or less dense, they are bent out of their straight course, or *refracted;* unless they should happen to pass from the one to the other in a direction perpendicular to the plane which separates them. This may be made evident by a very simple experiment. Place a coin or any heavy body (*a*, Fig. 194) at the bottom of a basin, and then retreat from it, until the coin is hidden by the edge of the basin; if water be then poured in, up to the level *c*, the coin will again become visible, although neither its own place, nor that of the observer, has undergone any change. The reason of this is, that the rays of light, as they pass out of the water, are bent downwards, or *from* the perpendicular; so that they reach the eye of the observer, when it is situated at a lower point than that which the rays would have reached, if they had proceeded in a straight line. Thus the eye of the observer, situated at the end of the line *a c*, could not see the coin in a straight line; because rays passing in that line would be interrupted by the opaque sides of the basin; but it receives the ray which was passing through the water in the direction *a d*, and which was bent downwards at the moment of quitting it. If the eye had been placed directly over the coin, however, so that the ray passing from the latter to it would have emerged from the water in a direction perpendicular to its surface, no change in the apparent place of the object would have been made by pouring in the water; since a ray that passes from one medium, to another however different, in a direction perpendicular to the surface which separates them, is not refracted. Those rays which pass out most nearly in this direction are refracted least, whilst those which pass out most nearly in the horizontal direction are refracted most.

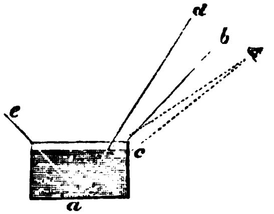

FIG. 194.

528. The general law of refraction, then, is,—that all rays passing from a dense to a rare medium are refracted *from* the perpendicular, the degree of change being less as they are near the perpendicular, and greater as they depart from it. On the other hand, when rays pass from a rare medium into a dense one, they are bent *towards* the perpendicular; and this in a greater or less degree, according as their direction is more distant from the perpendicular, or nearer to it. Thus, in Fig. 194, we will suppose the point *a* to be the position of the eye of a Fish; and the end of the line *a c* (previously occupied by the eye of the observer) to be the position of an Insect in the air. Now this insect will not be seen by the fish in its true place; for a ray passing from it to *c* would be so bent out of its course, as not to reach the point *a*. The direction in which it is really seen is *a d;* for the ray proceeding from the object to the surface of the water, there undergoes such a refraction, that it is bent downwards to *a;* and, as we always judge of the place of an object by the direction in which the rays last come to the eye, the insect is seen by the fish at *d*, that is, considerably above its real place (§. 476).

529. When the surface which separates the two media is not flat, but is convex or concave, (bulging or hollowed out,) a very important alteration is produced in the direction of the rays that fall upon it. Thus we shall suppose that three diverging rays, issuing from a point, *a*, (Fig. 195), and traversing the air, strike upon a *convex* surface of glass, *b b′*. The central ray *a c* falls upon the glass in a direction perpendicular to its surface at that point, and passes on unchanged in its

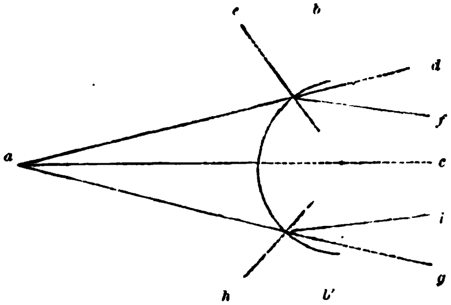

FIG. 195.

course. But the ray *a d* falls upon the surface very obliquely; and consequently in entering the glass, it will be bent towards the line *e*, which is perpendicular to the surface at the point where it enters, and will pass onwards in the direction *f*. In the same manner, the ray *a g* will be refracted into the direction *i*. Hence these rays, now *converging*, would be found, if prolonged, to meet each other again; and the point at which they meet is termed the *focus*. To this point all the other rays, which fall upon the convex surface, at a moderate distance from the central ray, will be also conducted.

530. On the other hand, if the surface of the glass, instead of being convex, is *concave*, the diverging rays which fall upon it will be made to diverge still more. Thus in Fig. 196, let *a* be the point whence the rays issue, and *b b* the surface of the lens; the central ray *a c* will pass on unchanged, as before; but the ray *a d* will be bent towards the perpendicular *e*, so as to pass on in the direction *f*; and the ray *a j* will be bent towards the perpendicular *h*, into the direction *i*. It is easy to understand that the change of direction will be greater, as the curvature of the lens is more considerable. Thus a convex lens has a long focus or a short focus (that is, brings rays to a focus at a greater or less distance from itself) according as the curvature of its surface is less or more considerable.

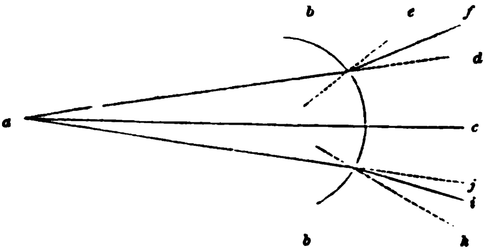

FIG. 196.

531. The rays issuing from every point in an object, and falling upon a convex lens, are brought to a focus on the other side of the lens; and thus a distinct image or picture is formed upon any screen placed at the proper distance to receive it,—every point in that image being the representative of the corresponding point in the object. But this image, according to the laws of Optics, will be *inverted*.

532. Now the Eye, in its most perfect form—such as it possesses in Man and the higher animals—is an optical instrument of wonderful completeness, designed to form an exact picture of surrounding objects, upon the expanded surface of the optic nerve, by which the impression is conveyed to the brain. As it is in the most perfect form of this instrument, that we are best able to judge of the uses of its different parts, it will be preferable to consider this in the first instance, and then to advert to the less complete forms, which we meet with in the lower animals.

533. The Eye of Man, and of all the Vertebrata, has a nearly globular form. The walls of the sphere are composed of three *coats*; whilst in its interior are found three *humours* of a more or less fluid character. The outer coat, named the *sclerotic* (*s*, Fig. 197), is tough and fibrous, and is destined to support and protect the delicate parts which it contains. It does not cover the whole globe, however; but gives place in the front of the eye, to a transparent lamina of cartilaginous structure (*c*), which is termed the *cornea*. The manner in which this cornea is set upon the sclerotic coat, serving as the continuation of it, may be compared to that in which a watch-glass serves as the continuation of the watch-case over the dial. The cornea is rather more convex than the rest of the sphere of the eye; so that the globe makes a slight additional projection in that part. When the sclerotic coat is removed, we come upon the second coat, which is termed the *choroid* (*ch*); this is much more delicate in its structure, and consists almost entirely of blood-vessels and nerves. It has a deep black colour, owing to its being covered with a layer of *black pigment*, which consists of *cells* that have

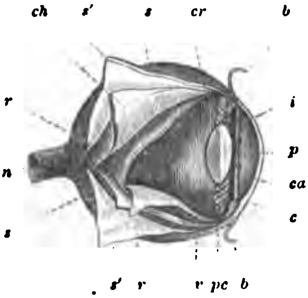

FIG. 197.—INTERIOR OF THE EYE.

c, cornea; *s*, sclerotic; *s′*, portion of the sclerotic turned back to show the subjacent parts; *ch*, choroid; *r*, retina; *n*, optic nerve; *ca*, anterior chamber; *i*, iris, *p*, pupil; *cr*, crystalline lens; *pc*, ciliary processes; *v*, vitreous humour; *bb*, conjunctiva.

the power of secreting a black granular matter in their interior.* This coat also changes its character in the front of the eye; being there continuous with the *iris*, or coloured portion (*i*), which forms a sort of curtain that hangs down behind the cornea. The surface of the iris is flat, or nearly so; and there is consequently a space between it and the cornea, like that which intervenes between the dial-plate and glass of a watch; this space is termed the *anterior chamber* of the eye. The iris is perforated in its middle by an aperture, termed the *pupil* (*p*). This aperture is always round in Man; but in animals whose range of vision is required to extend widely in a horizontal direction, (such as the Ruminantia, and others which feed upon herbage,) it is an ellipse with the long diameter horizontal; whilst in animals which rather seek their food above or below them, (such as the Cat and other Carnivora, which naturally live among trees and high places,) the pupil is an ellipse, whose long diameter is vertical.

534. By the contraction and relaxation of certain fibres in the iris, the size of the pupil is changed, according to the degree of light to which the eye is exposed; the pupil being made to contract in a strong light, in such a manner as to exclude the rays that would be superfluous, and to prevent too many from falling upon the expansion of the optic nerve; whilst it dilates in a faint light, so as to admit as many rays as possible. If we notice the pupil of a Man who is looking towards the mid-day sun, we shall see that it is contracted to a small round speck; but the pupil of a Sheep would be contracted, in similar circumstances, into a horizontal slit; and the pupil of a Cat into a vertical one. The alteration in the size of the pupil, in accordance with the degree of light, may be easily observed, by stationing one's self at a window provided with shutters, and holding a looking-glass in the hand. If the light be at first strong, the pupil will be seen in a contracted state; but if the shutters be gradually closed, so as to diminish the amount of light that falls upon the eye, the pupil will be seen to enlarge; and it will

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* Similar pigment-cells, having great variety in their form, are to be found composing the black spots on the skin of the Frog, Water Newt, &c.

diminish again when the shutters are re-opened. The blackness which the pupil always presents, in the healthy state of the eye, is due to our seeing the black lining of the back of the eye through it. In many quadrupeds, the black pigment is replaced, in one portion of the eye, by a layer of a bluish colour, having an almost metallic lustre; and from this we see the light brilliantly reflected, when we look at their eyes in certain directions. The back of the iris is always covered with black pigment, the use of which is, to absorb the rays that would otherwise be reflected from one side of the interior of the eye to another, rendering the image indistinct.

535. On turning back the choroid coat, we come to the third layer (*r*), of which the wall of the eye is composed; this is an extremely delicate film, chiefly consisting of nervous fibres which spread out from the optic nerve (*n*); and it is called the *retina* (or net). It advances nearly as far as the iris; but it is deficient in the front of the eye.

536. The cavity of the globe is occupied by three *humours* of different consistence,—the *aqueous*, *vitreous*, and *crystalline*. The *aqueous* humour is nearly pure water, being nothing else than the serum of the blood very much diluted; it occupies the anterior chamber (*ca*), and a small space behind the iris, in front of the crystalline lens. The *vitreous* humour (*v*) resembles thin jelly in consistence, and occupies the greater part of the globe of the eye behind the iris. The *crystalline* (*cr*) is of much firmer consistence, resembling very thick jelly, or soft gristle; it has the form of a double convex lens, the posterior surface of which is more convex than its anterior; and hence it is commonly known as the *crystalline lens*. It is suspended in its place by a set of little bands proceeding from the choroid coat, and known as the *ciliary processes* (*pc*).

537. The cornea is covered externally by a membrane (*bb*) termed the *conjunctiva*. This membrane is perfectly transparent where it covers the cornea, and seems like the outer layer of it; the front of the sclerotic also is covered by it, and it is there semi-opaque, having a whitish colour. The membrane does not pass back over the globe of the eye, however, but bends forward

again, as seen at *bb*, so as to form the lining of the eyelids, at the edge of which it becomes continuous with the skin. Thus the smooth surfaces of the eye and of the under side of the lids, are both formed by this membrane; the mucous secretion from which, serves to diminish the friction of one upon the other. But the smallest particle of any hard substance, which may become interposed between these surfaces, produces great irritation. It cannot pass far backwards, however, on account of the bend of the membrane at *bb;* and thus it may be always removed (if loose) with little difficulty. The lower lid can be easily drawn down, so as to expose the membrane as far as this bend; and any loose particle that is lying upon its surface may thus be detected and removed. But the upper lid, being longer, cannot be drawn out sufficiently for this purpose; and it is necessary to *evert* it, or turn it inside-out. As the knowledge of the mode of performing this very simple operation will often save a good deal of suffering, it will be here described. Nothing more is necessary than to close the upper lid—not forcibly, however; next to make pressure upon its upper part with a pencil, bodkin, knitting-needle, or other hard body of small diameter; and then, taking hold of the eye-lashes, to draw the lower edge of the lid forwards and upwards. By a dexterous movement of this kind, the lid may be everted without any pain,—a little temporary discomfort being all that the displacement occasions; its lining membrane is then exposed, and any offending particle may be readily removed.

538. The globe of the eye is moved by six muscles, which are lodged within the bony cavity or *orbit*, hollowed out in the skull. All these muscles, except one, originate at the back of the orbit, and are inserted into the sclerotic coat, near its front, by broad thin tendons. Four of them are termed *recti* or straight muscles. One of these, the *superior rectus* (*e*, Fig. 198), is inserted at the upper part of the eye, and consequently by its contraction rolls the globe upwards; another, the *inferior rectus* (*d*) produces a corresponding movement downwards. A third, the *internal rectus* (which could not be shown in this figure) rolls the globe inwards or towards the nose; whilst a

fourth, the *external rectus*, (the cut extremity of which is seen at *f*), turns it outward. Besides these, there is a remarkable muscle, the *superior oblique* (*h*), which originates at the back of the orbit, comes forwards to the front, where its tendon passes through a pulley, and then turns backwards to be inserted into the sclerotic coat, at a point considerably behind the pulley. The action of this muscle will be to roll the globe downwards and somewhat outwards. The sixth muscle, termed the *inferior oblique* (*g*), does not arise like the rest from the back of the orbit, but from its lower border; and its action is to roll the eye upwards and inwards. Of these muscles, the superior, inferior, and internal recti, together with the inferior oblique, and also the elevator muscle (*i*) of the upper eyelid, are supplied with motor nerves by the *third* pair (§. 458); whilst the superior oblique has a nerve to itself, the *fourth;* and the external rectus has another nerve to itself, the *sixth*.

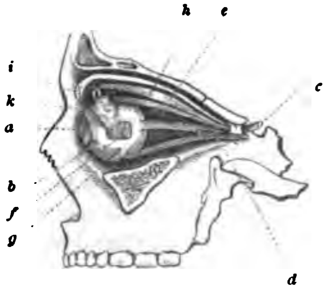

FIG. 198.—VERTICAL SECTION OF THE ORBIT, showing the globe of the eye and its appendages; *a*, cornea; *b*, sclerotic; *c*, optic nerve; *d*, inferior rectus muscle; *e*, superior rectus; *f*, cut extremity of the external rectus; *g*, end of the inferior oblique; *h*, superior oblique; *i*, elevator of the upper lid; *k*, lachrymal gland.

539. The relative actions of these muscles and nerves are not yet fully understood. There is this very peculiar circumstance attending the movements of the two eyes,—that although they are *harmonious*, they are seldom *symmetrical*. Thus, when we direct our eyes towards an object on one side of us, they move harmoniously, that is, with a common purpose; but their movement is not symmetrical, for one globe is rolled inwards by the internal rectus, whilst the other is rolled outwards by the external rectus. These two different actions seem to be instinctively connected, and to be guided by the sensations which are received through the two eyes respectively.* It is only when they both move directly upwards, or directly downwards,

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* See the Author's Principles of Human Physiology, §. 251, 252.

that their movements are at the same time harmonious and symmetrical. It may be shown that two of the recti muscles, acting in conjunction with one of the oblique, may produce (according to the laws of the composition of forces, MECHAN. PHILOS. §. 162) any of the motions of the globe; and it has been suggested that the symmetrical movements of the eyes are produced (in all cases in which they are not harmonious) by the *voluntary* action of one set, acting upon the eye which is directed towards the object; whilst the other eye follows in the same direction by the *instinctive* movement of the other set.

540. The eyebrows, eyelids, and eyelashes, serve in various ways for the protection of the eyes. In Birds and Reptiles there is a third eyelid, which is drawn *across* the eye by a muscle that passes through a loop in it. This *nictitating membrane*, as it is termed, is semi-transparent; and it serves to protect the eye from the too-powerful rays of light, without destroying the power of vision. The upper and lower eyelids of the Mammalia, and the nictitating membrane of Birds and Reptiles, are very frequently drawn over the front of the globe, during the waking state, for the purpose of sweeping from it the dust and other accidental impurities, which would otherwise be injurious. Beneath the upper eyelid, in the upper and outer portion of the orbit, is situated the *lachrymal gland* (*k*, Fig. 198); this is continually pouring out a watery secretion over the globe of the eye, which serves to wash from it these impurities, and to keep it moist. It is only, however, when the quantity of this secretion is increased by mental emotion or by irritation in the eye itself, producing a flow of tears, that we become conscious of its existence. It is ordinarily drawn off as fast as it is formed, by a curious apparatus situated at the inner border of the eye. If the edges of the lids be carefully examined, there will be seen upon each of them, close to the inner corner of the eye, a minute spot, which is the entrance to a small canal, termed the *lachrymal duct*. The two ducts, one commencing at the corner of the upper lid, and the other at the lower, soon unite into one canal, which swells out into a sort of reservoir, the *lachrymal sac*, that lies upon the side of the upper part of the nose; and from this

reservoir a canal passes down, through the bones of the nose, into its cavity. By this apparatus, the fluid which is poured by the lachrymal gland over the exterior of the eye, is drawn off at the interior, after washing its surface; whence it is carried into the nose, and is got rid of by the current of air that passes through its passages in breathing. The edges of the lids meet in such a manner, when they are closed, as to form a sort of gutter or channel, along which the lachrymal secretion flows from their outer to their inner corner during sleep.

541. Having thus described the structure of the Eye, and the general actions of the parts by which it is adapted to the performance of its remarkable function, we shall examine into the details of this function; in other words, into the nature of *vision*.

542. It is through the medium of the light they emit, that we are enabled to take cognizance by the Eye of the forms, sizes, colours, and positions of surrounding objects. Some of these are self-luminous; that is, they give off light from themselves, when that from all other sources is excluded. This is the case with the Sun, and with bodies in a state of combustion; as well as with those that are phosphorescent, which may probably be regarded as in a state of slow combustion. But other bodies transmit to us only that light which their surfaces reflect from self-luminous bodies; and hence, when they are excluded from the influence of the latter, they are not seen. Thus in day-light, the light of the sun is reflected to us from the clouds, from the surface of the earth, and from all terrestrial objects,—the more powerfully, in proportion as their respective surfaces are more highly polished or of brighter colours: but if we place ourselves in a room, from which the light of the sun is entirely excluded, we can see no objects, because no luminous rays are reflected by them to our eyes.

543. The rays of light which diverge from the several points of any object, and fall upon the front of the cornea, are refracted by its convex surface, whilst passing through it into the eye, and are made to converge slightly. They are brought more closely together by the crystalline lens, which they reach after passing through the pupil; and its refracting influence, together with

that produced by the vitreous humour, is such as to cause the rays that issued from each point to meet in a focus on the retina. As every point is thus represented in its proper position relatively to others (except that those which were above are now below, and *vice versâ*), a complete inverted image or picture of the object is formed upon the retina. This is shown in Fig. 199; where, for the sake of convenience, two rays only are represented as issuing from each of the two extremities of an object, *a c*. These rays cross each other in the middle of the eye, those from *a* being brought to a focus at *b*, and those from *c* at *d*; and as all the other rays are refracted in the same manner, a complete inverted picture of the object is formed at the back of the eye.

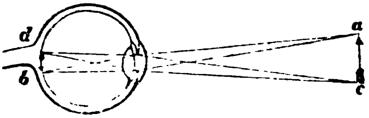

FIG. 199.

544. That this is really the case, may not only be inferred, but proved. If the eye of a Rabbit be removed from its socket, and cleansed of the muscles, fat, &c. adherent to its back part, and a candle be then brought in front of it, the transparency of the sclerotic coat will allow the image of the candle, that is formed upon the retina, to be distinctly seen. Or, if we take the eye of a Sheep or an Ox, and after cleansing it in the same manner, we cut out from the back of it a portion of the sclerotic and choroid coats, covering the part of the retina thus left bare, with a piece of tissue-paper (for the purpose of keeping in the vitreous humour, without interrupting our view of the image), a distinct but inverted miniature picture of all the objects in front of the eye will be seen at its back. It is necessary in these experiments that the eyes should be taken from animals recently killed; as the cornea and humours soon lose their transparency, and the distinctness of the picture is consequently impaired.

545. The black pigment, which is situated immediately behind the retina,—that is, in contact with its external surface,—is destined to absorb the rays of light, immediately that they have passed through the retina; so as to prevent them from

being reflected from one part of the interior of the globe of the eye to another, which would cause a great confusion and indistinctness in the picture. Hence it is that, in those individuals (both among Man and the lower animals) in whose eyes this pigment is deficient, vision is extremely imperfect. The eyes of those individuals (termed Albinos), derive, from the absence of pigment, a very peculiar appearance. The iris does not possess its ordinary colour; but, owing to the large quantity of minute blood-vessels which it contains, it presents a bright red hue. The choroid coat, seen through the pupil, has exactly the same aspect; so that the pupil is not readily distinguished. During the day, the vision of these Albinos is very indistinct, and the glare of light is painful to them; and it is only when twilight comes on, that they can see clearly and without discomfort.

546. The eye is a much more perfect optical instrument than we might be led to suppose, from the cursory view we have hitherto taken of its functions; for by the peculiarities of its construction, certain faults and defects are avoided, to which all ordinary optical instruments are liable. One of these, termed *spherical aberration*, results from the fact, that rays falling upon the central and outer parts of an ordinary convex lens, whose surfaces form part of a sphere, are not brought to meet in one point,—the focus of the central portion being rather more distant than that of the outer part. This is shown in Fig. 200, where

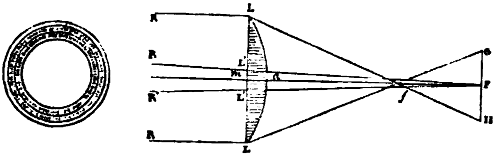

FIG. 200.

L L is the lens, R L, R L, are rays falling upon its circumference, and R′ L′, R′ L′, are rays falling near its centre. The former set of rays meet in *f*; whilst the latter pass on to F, before they meet in a focus. This may be shown by covering the central and outer portions of the lens, alternately, with some opaque substance, which shall stop all the rays of light proceeding through it. When the central portion is covered, a distinct image will be formed at *f*, by the rays falling upon the outer portion; and when the outer portion is covered, a distinct image will be formed at F, by the rays that have passed through the inner portion. But when the whole lens is employed, no distinct image is formed anywhere; for if a screen be held at *f*, it will receive, not only the rays which are brought to a focus at that point, but also the rays which are going on to meet at F; and, on the other hand, if the screen be held at F, it will receive, not only the rays which are brought to a focus there, but also those which, having met at *f*, have crossed and passed on to G and H.

547. Now this indistinctness is ordinarily got over in practice, by employing only the *central* portion of the lens; so that only those rays which correspond to R′ L′, R′ L′, shall pass through it. This we observe in ordinary Microscopes and Telescopes;—a *stop* or perforated partition being interposed behind the lenses, so as to allow the light to pass through only a small aperture in their centre. By this plan a great deal of light is cut off; and the image is rendered dark. The spherical aberration may be completely corrected, however, by a certain adaptation of two or more lenses, whose surfaces have different curvatures; the effect of which is, to bring all the rays that have passed through every part of this compound lens to the same focus. Now this very adjustment is made in the eye, by the arrangement of the curvatures of the cornea and of the two surfaces of the crystalline lens; and in the well-formed eye it is so perfect as to produce complete distinctness in the image or picture formed upon the retina. The only case in which this would not occur is, when an object is brought near the eye; for then the rays diverge from each other at a greater angle than when the object is at a moderate distance; and those which fall upon different parts of the lens would not be all brought to the same focus. This error is corrected by the contraction of the pupil, which takes place involuntarily when we bring an object near the eye, and thus cuts off the rays that would otherwise render the picture indistinct.

548. But there is another imperfection to which ordinary optical instruments are liable, that is completely corrected in the eye. If we look through a common Microscope, especially when a high power is employed, by the light of a lamp or candle, we see that the edges of the image are bordered by coloured fringes, which very much impair its distinctness, and prevent it from being seen in its true aspect. This is the result of what is termed *chromatic aberration;* and it results from the fact, that the rays of different colours, which are all blended in ordinary colourless light, are refracted by the same lens in different degrees, so as to be brought to a focus at different points. Thus we will suppose that the lens L L (Fig. 200) has been corrected for *spherical* aberration; and that R L, R L, are violet rays falling upon it, whilst R′ L′, R′ L′, are red rays. The former are capable of being refracted in a much higher degree than the latter; so that they are brought to a focus at *f*, whilst the others do not meet until F. Hence if a screen be placed to receive the image at *f*, the picture will be formed by the violet rays only; and it will be surrounded by red fringes, occasioned by the red rays which are passing on to their focus at F. On the other hand, if the screen be placed at F, the picture will be chiefly formed by the red rays; and will be surrounded by violet fringes, produced by the violet rays, which, having met in *f*, have crossed and passed on to G and H. Now as from each point of almost every object, proceed rays in which the differently-coloured rays are blended, the refraction of an ordinary lens produces a separation of these, and a consequent indistinctness and false colouring in the picture. This is particularly the case with regard to the rays that pass through the outer portion of the lens; for, as these are subject to greater change in their direction than are those which pass through its centre, the separation of the differently-coloured rays of which they are composed is more considerable.

549. In practice, this error is got over, like the preceding, by very much contracting the aperture of the lens; so that only the central rays, in which the colours are but little separated, are allowed to pass. But it may be perfectly corrected by combining lenses formed out of different materials, which possess

a different refracting power; the errors of these being made to counterbalance one another. Such lenses, which are termed *achromatic*, are now employed in all superior Telescopes and Microscopes; and a most perfect combination exists in the Eye, the different density of whose humours is adapted in such a manner as completely to answer this purpose. The contraction of the pupil, which takes place when we look at a very near object, prevents the only imperfection which could occur; and thus the picture on the retina, in a healthy eye, is always rendered free from false colours. It is said that the first idea of uniting glasses of different kinds, so as to produce an achromatic lens, was taken from the Eye; and this is not at all improbable. In this, as in many other instances, Nature has served as a guide to Art; or, in other words, the Divine Artificer has thus condescended to teach the human workman.

550. There is another wonderful arrangement in the healthy Eye, which the optician can only imitate in his instruments, in a very bungling manner. It is that by which the eye adapts itself to view objects at different distances from it, with equal distinctness. If we look at a near object with a Telescope, adjusting the instrument so as to see it distinctly, and then turn it towards a remote object, we shall not see the latter with equal clearness, until the instrument has been again adjusted. If we then turn it back to the nearer object, we shall find that the change in the adjustment occasions the representation of it to be now indistinct; and in order to bring back the image to its former clearness, it is requisite to re-adjust the instrument to its first condition. This is a necessary consequence of the optical law, that the distance of the image from the lens which forms it, varies with that of the object,—being increased as the object is brought nearer, and diminished as it recedes. If the Eye were constructed in the same manner, we should not be able to see distinctly, without the aid of artificial assistance, at any other distance than that for which it is adjusted. Hence if a perfect picture of an object situated at 12 inches distance from the eye, were formed upon the retina, we should not be able to see it clearly when brought to the distance of 6 inches, nor when

removed to the distance of six feet; because, in the first of these cases, the rays would not be brought to a focus upon the retina, but at a point behind it (if they were allowed to pass on unchecked); whilst in the second, they would be brought to a focus at a point nearer than the retina, and would consequently begin to separate again before they reach it.

551. But the healthy eye possesses a power of perfect adjustment to the viewing of objects situated at different distances; and this without any effort or intention on our parts, but, as it were, by an instinctive operation. Of the mode in which this adjustment is accomplished, nothing certain is yet known; but it is probable that either the position or the form of the crystalline lens undergoes a change; by which either its distance from the retina, or its refracting power, is increased when the object is brought near, and diminished when it is carried to a greater distance: so that, under all circumstances, the picture is formed distinctly upon the retina, and vision is consequently clear. That such a change really takes place, we may readily convince ourselves, by looking at a near and a distant object placed in the same line,—a pencil-case, for instance, held up at a few inches from the eye, and a chimney half a mile off. We shall find that no effort of attention will enable us to see them both distinctly at the same time; but that, on whichever of the two objects we fix our eyes, we shall see *it* clearly, whilst the other becomes indistinct.

552. In advanced life, however, the convexity of the cornea, and the refracting power of the humours diminish; and the eye can no longer accommodate itself to near objects, their rays not being brought to a focus by the time that they reach the retina. But as it is still able to see distant objects clearly, it is said to be *long-sighted*. By the use of a convex glass, however, adapted to supply that additional amount of refraction which is required, near objects may be distinctly seen.—A contrary state of the eye not unfrequently exists, in which the cornea is too convex, and the refracting power of the humours is too high; from which it happens that the rays proceeding from distant objects are brought to a focus too soon, so as to cross each other before they

reach the retina. But as such an eye can form a very distinct picture of a near object, it is said to be *near-sighted.* This imperfection is remedied by interposing a concave lens between the object and the eye; by which its refracting power is diminished to the necessary degree.

553. In the choice of spectacles, or eye-glasses for these purposes, particular care should be taken, that they are not too powerful; since great mischief is frequently done to the eye, by the employment of lenses of too great a curvature. A person who in youth and middle age has enjoyed good sight, very commonly finds it necessary to employ spectacles for assistance in reading and writing, as his age advances towards 50 years; and he should be very cautious, when first availing himself of their assistance, to employ those of the longest focus. As his age advances, it will be necessary to substitute more powerful lenses for these; but this should be done very gradually; and in no instance should a glass be employed that produces any apparent enlargement in the object, its proper use being only to render the object distinct. The evil influence of using spectacles of too high a power, soon manifests itself in the *strained* feeling which the eyes experience for some time; but this feeling at last subsides, in consequence of the eye having adapted itself to the glasses, and thus undergone a change which it might otherwise have taken years to produce. In this manner the eyes of a person at 60 may be brought to the state, which, under more careful management, might have been deferred ten or fifteen years longer.—Similar remarks apply to the use of concave lenses by short-sighted persons. They should never be employed of a higher power, than is requisite to see objects with distinctness, when at a moderate distance; and on no account should any glasses be used, that diminish their apparent size. As age advances, the eyes of short-sighted persons usually become more flattened; and they are then able to adapt themselves to objects at a variety of distances. Persons who have been short-sighted when young, are not unfrequently able to see distinctly at an advanced age, without the assistance of convex glasses.

554. Some interesting observations on the limits of vision,

in regard to the minuteness of the size of the particles which can be distinguished with the naked eye, have been made by the Prussian naturalist, Ehrenberg, to whose microscopical inquiries we are indebted for a large part of our present knowledge of the structure and habits of Animalcules. The smallest particle of a white substance distinguishable by the naked eye upon a black ground, or of a black substance upon a white ground, is about the 1-400th of an inch square. It is possible, by the closest attention, and by the most favourable direction of the light, to recognise particles that are only 1-540th of an inch square; but without sharpness or certainty. But particles which strongly reflect light may be distinctly seen, when not half the size of the least of the foregoing; thus, gold-dust of the fineness of 1-1125th of an inch may be discerned with the naked eye in common daylight. When particles that cannot be distinguished by themselves with the naked eye, are placed in a row, they become visible; and hence the delicacy of vision is greater for *lines* than for single particles. Thus, opaque threads of no more than 1-4900th of an inch across,—or about half the diameter of the silkworm's fibre, may be discerned with the naked eye, when they are held towards the light.

555. The degree in which the *attention* is directed to them, has a great influence on the readiness with which very minute or distant objects can be perceived; and there is a much greater variation in this respect amongst different individuals, than there is in regard to the absolute limits of vision. Many persons can distinctly see such objects, when their situation is exactly pointed out to them, who cannot otherwise distinguish them. There must be few who have not experienced this, in regard to a balloon or a faint star, in a clear sky, or a ship in the horizon; we easily see them after they have been pointed out to us; but we withdraw our eyes for a few minutes, and then search in vain for them, until they are again pointed out to us by some one who has been watching in the interval. The faculty of rapidly descrying such objects, depends upon the habit of using the eyes in search of them; thus a seaman will distinguish land, when to the landsman there is no appearance more distinct than

that of a faint cloud on the horizon, with (to him) no definite outline; or he will recognise the course and rig of a distant ship, which, to the landsman appears but as a white speck on the ocean: yet the landsman, placed before a piece of delicate machinery, might be able to astonish the seaman, by distinguishing the forms and movements of minute parts, which to the latter appear only as a confused mass.

556. The picture formed upon the retina, closely resembles that which we see in a camera obscura. It represents the outlines, colours, lights and shades, and relative positions, of the objects before us; but these do not necessarily convey to the mind the knowledge of their real forms, characters, or distances. It would appear, from the actions of the lower animals, that many of them have the power of *intuitively* or *instinctively* determining the latter from the former, from the moment when they come into the world; thus a Fly-catcher just come out of its egg, has been seen to make a successful stroke with its bill, at an insect which was near it. If it were not so, those animals, which are thrown from the first upon their own resources, must perish almost inevitably; being starved by want of food, during the time required for them to learn how to obtain it. But this is well known not to be the case in regard to Man. The infant is educating his *senses*, long before any indications of *mind* present themselves. By the combination, especially, of the sensations of sight and touch, he is learning to judge of the nature of the surfaces of objects, as they *feel*, by the *appearance* they present,—to form an idea of their distance by the mode in which his eyes are directed towards them (§. 563),—and to estimate their size, by combining the notions obtained through the picture on the retina, with those he acquires by the movement of his hands over their different parts. A simple illustration will show, how closely the ideas excited by the two sets of sensations are blended in our minds. The idea of *smoothness* is one which has reference to the touch; and yet it constantly occurs to us, on looking at a surface which reflects light in a particular manner. On the other hand, the idea of *polish* is essentially visual, having reference to the reflection of light from the surface

of the object; and yet it would occur to us from the sensation conveyed through the touch, even in the dark.

557. That this combination is *not* formed *intuitively* in Man, but is the result of experience, is particularly evident from cases, in which the sense of sight has been wanting during the first years of life, and has then been obtained by an operation. Several such cases are now on record. The earliest, which still remains the most interesting, is one recorded by Cheselden, a celebrated surgeon at the beginning of the last century. The youth (about 12 years of age), for some time after tolerably distinct vision had been obtained, saw everything *flat*, as in a picture; the impression made upon his retina being simply transferred to his mind: and it was some time before he acquired the power of judging, by his sight, of the real forms, characters, and distances of objects around him. Thus, among other interesting circumstances, it is mentioned, that he was well acquainted with a Dog and a Cat by *feeling*, but could not remember their respective characters when he *saw* them; one day, when thus puzzled, he took up the Cat in his arms and felt her attentively, at the same time looking steadfastly at her, so as to associate the two sets of ideas; and then, setting her down, said, "So, puss, I shall know you another time." A similar instance has come under the Author's own knowledge; but the subject of it was scarcely old enough to present facts of so striking a character. One curious circumstance, however, may be mentioned, as fully bearing out the view here given. The lad had been accustomed to find his way readily about his father's house, by the use of his hands; and for some time after his sight was tolerably clear, he continued to do the same, being evidently puzzled, rather than assisted, by the impressions conveyed through his new sense; but, when learning a new locality, he employed his sight, and evidently perceived the increase of facility which he derived from it. Hence we can have little hesitation in deciding upon the question, which has perplexed many able reasoners, whether a person born blind, who was able by the sense of touch to distinguish a cube from a sphere, would, on suddenly obtaining his sight, be able to distinguish them by the latter sense. This question was answered

in the *negative*, by the celebrated mental philosopher, Locke, and with perfect justice.

558. We shall now inquire into the mode in which we form our notions of the nature, sizes, distances, &c., of external objects, from their pictures impressed upon our retina. The first question is one on which a vast amount of discussion has taken place, with very little satisfactory result. It is,—why are the objects which we see, represented to our minds in their true erect position,—their images upon the retina being inverted? Various replies to this question have been proposed at different times; and amongst others, it has been actually assumed, that the Infant really does see objects inverted, and that his idea is only corrected by experience. The cases alluded to in the last paragraph, however, satisfactorily prove this assumption to be incorrect; since, although the individuals saw everything upon the same plane, as in a picture, the representation was erect from the first. The various other solutions that have been proposed, although at first sight appearing to possess more or less truth, are all open to objection; and we are obliged, therefore, to have recourse to the doctrine of *instinct* or *intuition* (§. 476), as the real explanation. When it is remembered how much knowledge the lower animals evidently derive, without any experience, from the visual representation which their eyes produce, it is not difficult to imagine that a small part,—that, too, which is most necessary for obtaining all the rest,—is intuitive in Man.

559. The same may be said of the cause of *single vision* (that is, of our seeing but one object) although the picture is *double*, being formed upon both retinæ. In animals which, like Man, look straight forwards, the field of vision of the two eyes is nearly the same; so that most of the objects seen with one eye will be seen with the other also. The objects at the right and left sides of the field of vision, however, are seen with the right and left eyes singly; yet we perceive no difference in the aspect of these, from that of the objects towards which both our eyes are directed. It is evident, then, that the pictures formed on the two retinæ are blended, as it were, by the mind, into a single perception. This seems to be, in part at least, the effect

of habit. When the images do not fall upon parts of the two retinæ which are accustomed to act together, *double vision* is the result. Thus if, when looking steadily at an object, we press one of the eyeballs sideways with the finger, the object is seen double. In the same manner, if an affection of the nerves or muscles of one eye (which may come on suddenly), prevents it from being directed to the same point with its fellow, double vision of all objects is the result. This is a not unfrequent symptom of disorder within the brain. If it continue, however, the individual becomes accustomed to the double images, or rather ceases to perceive that they are double; probably because the mind becomes habituated to receive the impressions from the two parts of the retinæ, which *now* act together. For if, after the double vision has passed away, the conformity of the two eyes is restored, as by the operation for the cure of squinting, there is double vision for some little time, although the two parts of the retina, which originally acted together, are now brought to do so again.

560. That the combination of the two images must be effected by an operation of the mind, is evident from another circumstance. It is easy to show, that no near object is seen by the two eyes in exactly the same manner. Thus, let the reader hold up a thin book, in such a manner that its back shall be exactly in front of his nose, and at a moderate distance from it; he will observe, by closing first one eye and then the other, that his view of it is very different, according to the eye with which he sees it. With the right eye he will see its back and right side—the latter very much foreshortened, but none of the left side; whilst with the left eye he will see its back and left side—the latter also foreshortened, but none of the right side. Hence, if he were to draw a perspective view of the object, as seen by each eye, the two delineations would be very different. But, on looking at the object with the two eyes conjointly, there is no confusion between these pictures; nor does the mind dwell upon either of them singly; but the union of the two intuitively gives us the idea of a solid *projecting* body—such an idea as we could have only acquired otherwise, by the exercise of the sense of touch.

561. That this is really the case, has been proved by experiments with a very ingenious instrument (invented by Professor Wheatstone), termed the Stereoscope. It consists of two plane mirrors, inclined with their backs to one another at an angle of 90°, the point of meeting being opposite to the middle of the forehead. Now if two drawings of any solid object, representing the different perspective views of it seen by the two eyes, be placed before these mirrors, in such a manner that their images shall be reflected to the two eyes respectively, and shall fall on corresponding parts of the two retinæ, in the same manner as the two images formed by the solid object itself would have done, so that their apparent places are the same,—the mind will perceive, not one or other of the single representations of the object, nor a confused union of the two, but a body projecting *in relief*, the exact counterpart of that from which the drawings were made. But if two dissimilar objects be thus presented to the two eyes, the mind perceives only one of them, the other being completely excluded for a time; but it commonly happens that, after one has been thus seen, the other begins to attract attention, and takes its place, without creating any confusion or intermingling of images, except at the moment of change. The power of the will may to a certain extent determine which object shall be seen; but not entirely; for if one picture be more illuminated than the other, it will be seen during a larger proportion of the time.—Some interesting experiments of this kind may be performed without the aid of mirrors; by simply placing the two pictures before the two eyes, and looking at each separately, by holding a piece of pasteboard or a thin book, with one edge upon the nose and forehead, and the other directed forwards, so as completely to separate the fields of view of the two eyes. By a slight effort, the apparent places of the two pictures may be made to coincide, so that one shall be made to cover the other, as when the Stereoscope is used; and the mental perception which results from the combination of the two images will be of the same kind as in the former case. There is a difficulty, however, in keeping the images in correspondence with one another, which renders the use of the Stereoscope much ~~~eferable.

562. It is, then, by the combination which is effected through a *mental* process of an instinctive kind, that the different pictures formed on the two retinæ are made to blend into one representation, which gives the idea of *projection*. We do not form this idea, except from reasoning and experience, when we look at a distant object; because the two pictures are then almost precisely the same; and hence it is impossible (without moving the head) to distinguish with certainty between a well-painted picture, in which the proportions, lights and shades, &c., are well preserved, and the objects it is intended to represent, if we are prevented from knowing that it *is* a picture. Some admirable illusions of this kind have been effected in the Diorama. But a slight movement of the head suffices to dispel the illusion; since by this movement a great change would be effected in the perspective view of an object,—a little of the side of a projecting buttress or column being seen, for instance, where only the front was perceived before,—whilst the image formed by a picture is but slightly affected.

563. Our idea of the *distance* of objects is evidently acquired by experience. An infant, when a bright object is held before its eyes, attempts to grasp it with its little hands; but obviously with no certain idea of its situation. The same is observed in persons, who have but recently acquired sight. Here, then, the impressions made upon the eyes have to be corrected by those received through the touch, before the power of judging of distances is acquired. But when it is once acquired, we can accurately estimate the relative distances of near objects, without using our hands. This we do chiefly, by the interpretation which we have learned to make, of the sensations which are occasioned in the muscles of the eyes, by their various actions. When we fix both our eyes upon a distant object, their axes (lines drawn through the centre of each cornea and pupil, backwards through the centre of each sphere,) are nearly parallel to each other. But when we direct them to a near object, the axes of the eyes meet in the point at which we are looking. This is very easily seen, by watching the eyes of another person, when fixed upon an object, first held at arm's length, and then brought nearer and

nearer to the middle point between the eyes; the two corneæ are at first directed nearly straightforwards; but they gradually turn inwards, as the object is brought nearer, and at last a very decided inward squint is produced, which disappears as soon as the object is removed. Thus, for objects within a moderate distance, the degree of convergence of the axes of the eyes, and the muscular sensations thereby produced, afford us sufficient means of judgment.

564. We perceive this in another, as well as in ourselves; for by observing his eyes, we can judge, not only of the direction, but of the distance, of the object he is looking at. Thus when a person, A., sees a friend, B., looking towards him, he can at once tell, by the appearance of B.'s eyes, whether he is looking at *him*, or at an object nearer or more remote; or whether, being in a contemplative mood, his eyes are fixed upon no definite object, but are looking into space. In the latter case, as in the case of blind persons in whose eyes there is no other indication of loss of sight, the peculiar vacant expression is due to the want of any convergence between the axes of the eyes, such as would indicate that they are fixed upon an object. The assistance which the joint use of both eyes affords in the estimation of distance, is evident from the fact, that, if we close one eye, we are unable to execute with certainty many actions, which require a precise appreciation of the distance of near objects,—such as threading a needle, or snuffing a candle. Instances are not unfrequent, in which persons have experienced this difficulty, before they were aware that they had lost the sight of one of their eyes.

565. In regard to distant objects, our judgment is chiefly founded upon their *apparent* size, if their *actual* size be known to us; and also upon the extent of ground, which we see to intervene between ourselves and the object. But if we do not know their actual size, and are so situated that we cannot estimate the intervening space, we principally form our judgment from the greater or less distinctness of their colour and outline. Hence, this estimate is liable to be very much affected by varying states of the atmosphere; a distant ridge of hills, for example, some-

times appearing to be more remote, at other times to be comparatively near, according as the air is hazy or peculiarly clear.

566. Our notion of the *size* of an object is closely connected with that of its distance. It is *founded* on the dimensions of the picture, which is formed by the object upon the retina; but it is corrected by the known or supposed distance of the object itself. Thus, I hold up a book at a certain distance from my eye, and it covers the whole of the opposite window; the *apparent* size of the picture of both is just the same, therefore; but knowing that the book is much nearer than the window, I infer that it is much smaller. Where we *know* their respective distances, the estimation of their real sizes is very easy; but this is not the case, when we only *guess* at their distances. Hence our estimate of the size of objects, even moderately distant, is much influenced by states of the atmosphere. Thus, if we walk across a common in a fog, a child approaching us appears to have the size of a man, and a man seems like a giant; for the indistinctness of the outline excites in the mind the idea of distance; and the same picture, supposed to be that of a more remote object, will give rise to the idea of greater size. The want of innate power in Man to form a true conception of either size or distance, is well shown by the effect produced on the mind unprepared for such illusions, by a skilfully-painted picture, the view of which is so contrived, that its distance from the eye cannot be estimated in the ordinary manner; the objects it represents are invested by the mind with their real sizes and respective distances, as if their real images were formed upon the retina. This illusion has been extremely complete, in some of those who have seen the panoramic view of London in the Colosseum. A lively and interesting account of it is given in the Journal of the Parsee Shipbuilders (from Madras) who visited England a few years since.

567. When a number of luminous impressions are made upon the retina at short intervals, they become blended into one, —the intervals being undistinguishable. Thus, when we rapidly move the end of a lighted stick in a straight line or circle, the impression produced is that of a band or ring of light; for the

impression made by the light, as it passes each point, remains for some time subsequently. If the stick be whirled round with sufficient rapidity, for it to reach any point a second time, before the impression made by its previous passage has departed, an unbroken circle of light is produced. By experiments made in this manner, we may determine the longest interval during which impressions remain on the sensorium; for if we find that a hot coal, whirling round at the rate of six times in a second, produces a continued circle of light,—but that the circle is broken, when it turns round only five times in a second,—we know that the length of the impression is 1-6th of a second. By experiments of this kind, it has been found, that the duration varies in different individuals, and in the same individual at different times, from 1-4th to 1-10th of a second. On this principle, several very ingenious toys have been constructed, in which two or more images are combined, by the rapid revolution of a wheel on which they are painted.

568. The impressions of variety of *colour* are produced by the different rays, which objects reflect to the eye; according to the principles that will be described in the Treatise on Optics. Some persons, whose sight is perfectly good for forms, distances, &c., are unable to discriminate colours. This is particularly noticed in regard to the *complementary** colours, especially red and green; so that such persons are not able to distinguish ripe cherries amongst the leaves of the tree, except by their form.

569. When the retina has been exposed for some time to a strong impression of some particular kind, it seems less susceptible of feebler impressions of the same kind; just as the ear, when it has been exposed to a series of very loud sounds (as the discharge of cannon in a naval engagement), is for some time deaf to fainter ones. Hence several curious visual phenomena result. If we look at any brightly luminous object, and then

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* White or colourless light is spoken of as composed of three primary colours, red, blue, and yellow. By the complementary colour is meant that which would be required to make white light, when mixed with the original. Thus, red is the complement of green (which is composed of yellow and blue); blue is the complement of orange (red and yellow); yellow of purple (red and blue); and *vice versâ* in all instances.

turn our eyes on a sheet of white paper, we shall perceive a dark spot upon it; the portion of the retina which had been affected by the bright image, not being affected by the fainter rays reflected by that part of the paper. If the eye has received a strong impression from a coloured object, the spot afterwards seen exhibits the complementary colour; thus, if the eye be fixed for any length of time upon a bright red spot on a white ground, and then be suddenly turned so as to rest upon the white surface, we see a green image of the spot. The same explanation applies to the curious phenomenon of coloured shadows. It may be not unfrequently observed at sunset, that, when the light of the sun acquires a bright orange colour, from the hue of the clouds through which it passes, the shadows cast by it have a blue tint. Again, in a room with red curtains, the light which passes through these produces green shadows. In both instances, a strong impression of one colour is made upon the general surface of the retina; and at any particular spots, from which the coloured light is excluded, that particular hue is not perceived in the faint light that remains, and its complement only is visible. The correctness of this explanation is proved by the fact, that, if the shadow be viewed through a tube, in such a manner that the coloured ground is excluded, it seems like an ordinary shadow.

570. Upon these properties of the eye are founded the laws of harmonious colouring; a full knowledge of which should be possessed by artists of every kind who are concerned with contrasts of colour, whether in pictures, architectural decorations, or even in dress. All complementary colours have an agreeable effect when judiciously disposed in combination; and all bright colours, which are not complementary, have a disagreeable effect, if they are predominant: this is especially the case in regard to the simple colours (red, blue, and yellow); strong combinations of any two of which, without any colour that is complementary to either of them, are extremely offensive. Painters who are ignorant of these laws, introduce a large quantity of dull grey into their pictures, in order to diminish the glaring effects which they would otherwise produce; but this benefit is obtained by a sacrifice of the vividness and force, which may be secured in

combination with the richest harmony, by proper attention to physiological principles.

571. The Eye is endowed with *common* sensibility (§. 487) by the fifth pair of nerves; and when this is paralysed, all parts of it are completely insensible to the touch, although the power of vision may remain unimpaired. It seldom preserves its healthy condition in this state, however; for the lachrymal and mucous secretions which protect its surface, are no longer formed as they should be; and inflammation, often terminating in the destruction of the eye, is the result.

572. The visual sensations obtained through the Eye have numerous and varied purposes among the lower animals. That they chiefly serve to direct their movements, is evident from observation of these movements; and from the fact that, when the eyes are covered or destroyed, most animals make little attempt at determinate motions, though they frequently exhibit a great deal of restlessness. There are a few Vertebrata, however, which do not possess perfectly-formed eyes, and which are consequently guided in their movements by other senses. This is the case with the Mole, which spends its whole life in burrowing beneath the ground; and also with the Proteus, and some others of the lower Amphibia, which inhabit the dark recesses of subterranean lakes and channels.

573. In the Articulated series of animals, we meet with eyes of a kind entirely different from those which have been previously described. In most Insects we notice a large black or dark-brown hemispherical body, situated on either side of the head; and in Crabs, Lobsters, &c., we see spherical bodies, of similar appearance, mounted on short

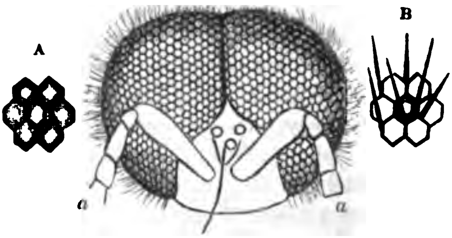

FIG. 201.—HEAD AND EYES OF THE BEE, SHOWING THE DIVISION INTO FACETS.
a, *a*, antennæ; A, facets enlarged; B, the same with hairs growing between them.

footstalks, which are capable of some degree of motion. When these are examined with the microscope, their surface is seen to be divided into a vast multitude of hexagonal (six-sided) facets. In a species of Beetle (Mordella) upwards of 25,000 of these have been counted; in a Butterfly, above 17,000; in a Dragon-fly, more than 12,500; and in the common House-fly, 4000. Every one of these facets may be regarded as the front of a distinct eye; which, however, instead of being globular, is conical in its form,—the front being the base of the cone, and the apex or point being directed towards the optic nerve, which swells out into a bulbous expansion, that fills a large part of the interior of the hemisphere. Each individual eye consists, therefore, of its facet, which (being convex on both surfaces) acts as a lens;—of the transparent cone behind this, which may be compared to the vitreous humour;—and of the fibre which passes from the bulbous expansion of the optic nerve, to the point of this cone. The several fibres are separated from one another by a considerable quantity of black pigment, which also fills up the spaces between the cones; and it is to this, that the black appearance of the whole compound eye is due. The various lenses or facets adhere together strongly at their edges, and may be readily separated from the remaining parts of the hemisphere, by soaking it in water for some time; a transparent horny membrane is thus obtained, in which the division into facets may be very beautifully shown, by transmitting light through it.

574. We must thus regard each of the cones, which, united together, constitute the hemispherical or globular mass,—in the light of a distinct eye, of which the horny facet constitutes the cornea, whilst the short transparent cone behind it is probably to be considered as the vitreous humour. Between the two there is, in some instances, a partition or diaphragm perforated by an aperture, which evidently represents the iris and pupil; and a lens-shaped body is occasionally found behind this, in the true position of the crystalline lens: in these instances, the number of cones is smaller than usual, and each individual eye is larger; so as to approach more nearly, both in its structure and mode of action, to the eyes of the kind previously considered. Where there

is no separate crystalline lens, the two surfaces of the cornea are both convex, so that each facet is a distinct lens; and it has been ascertained that the focus of this lens is exactly equivalent to the length of the transparent cone behind it; so that the image it produces, will fall upon the extremity of the filament of the optic nerve, which passes to its apex. The rays which have passed through the several prisms or separate corneæ, are prevented from mixing with each other, by means of the layer of black pigment which surrounds each cone; and thus no rays, except those which correspond in direction with the axis of the cone, can reach the fibres of the optic nerve. Hence it is evident that each separate eye must have an extremely limited range of vision, being adapted to receive but a very small collection of rays, proceeding from a single point in any object; and as these eyes are usually immoveable, the animals which possess them singly would be very insufficiently informed of the position of external things. But by the vast multiplication in the number of the eyes, their defects are compensated; a separate eye being provided, as it were, for every point to be viewed. And it is quite certain, from observation of the movements of Insects, that their vision must be very perfect and acute*.

575. Although these Compound Eyes exist in all Insects and most Crustacea, Arachnida, and Myriapoda, they are in general not the only organs of vision which these animals possess. Most of them are also furnished with several simple eyes, analogous in their structure to those of higher animals, but less complex and perfect in their organisation; these are for the most part disposed on the back of the head; they are largest in Spiders. The larvæ of some Insects possess the simple eyes

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* It is commonly believed that each of these compound eyes produces its own image of the same external object, as do *our* two eyes; but from the description here given of their separate directions when united, it is evident that, in no two of them, can an image of the same object be formed at the same time. The membrane formed of all the lens-like corneæ united together, when separated from the other parts of the eye, and flattened out, has the properties of a multiplying-glass, each lens forming a distinct image of the same object; but this is not the case when they are arranged in their natural position, because no two of them then have the same direction.

without the compound; the latter being only developed at the time of the last metamorphosis. The simple eyes of Insects do not appear to be nearly so efficient, as instruments of vision, as are their compound ones; for when the latter are covered, the animals seem almost as perplexed, as if they were perfectly blinded. Simple eyes, closely resembling those of Insects in structure, are found in most of the Mollusca which possess a head,—namely in the Gasteropods, Pteropods, and Cephalopods; those of the last class present an evident approach to the eyes of Fishes, in the greater completeness of their structure, and in their adaptation for distinct vision. In many of the lower Mollusca, as in the Rotifera and several Annelida, and also at the end of the arms of the Star-fish, red spots may be seen, which appear to be rudiments of eyes; but no distinct organs of vision can be seen in the Zoophytes and lowest Mollusca; although many of them appear very sensible to the action of light.

CHAPTER XII.

ANIMAL MOTION.

576. THE different modifications of the faculty of Sensation, which have been described in the preceding chapter, enable Man and other Animals to become acquainted with what is going on around them. But their connexion with the external world is not confined to this faculty; for if they possessed it alone, they would be nearly as *passive* as are Plants,—experiencing, it is true, pain and pleasure from their sensations, but not having the power of avoiding the one or procuring the other. They are endowed, however, with another faculty, that of spontaneous movement; which serves the double purpose, of enabling them to act upon the inanimate world around them, and of communicating to each other their feelings and ideas. Thus, if we find ourselves scorched by a flame, we either withdraw our bodies from it, under the direction of the *instinct* which leads us to avoid suffering; or we set about to extinguish the fire, by an act of the *will*, founded upon our knowledge of its injurious tendency. The Plant, even if it had sensation (which some naturalists have supposed), could do neither of these things. Again, it is entirely by the movements concerned in speech, by those giving expression to the countenance, and by the gestures of the body, that we convey to beings like ourselves a knowledge of what is passing in our own minds; of this power, we know that Plants are entirely destitute; and it is possessed in a very limited degree by the lower Animals.

577. The movements of Animals are effected by the action of a peculiar property, with which different beings seem to be endowed in proportion to their sensibility; this property is

termed *contractility;* and it consists in the power which certain parts of the body possess, of contracting suddenly when excited to do so, and of afterwards lengthening again by relaxation or slackening. In some animals of extremely simple structure, such as the *Hydra* (Fig. 1), all parts of the body appear equally susceptible of thus contracting; but when we rise a little in the animal scale, we find that this property is nearly restricted to a peculiar tissue, of which it forms the peculiar endowment; this tissue is commonly known as *muscular fibre.* In Vertebrated animals, the muscles, which are the active instruments of all their movements, form the greater part of the mass of the body, and constitute what is commonly known as the flesh or meat of animals. In the Mollusca, these muscles are for the most part few in number. Among the lower classes of that group, this tissue exists only in the mantle, in the muscles which draw the valves of the shell together, in the foot, and in the parts about the mouth. But in the Articulated tribes, the muscles are very numerous, and form (as in Vertebrata) a large part of the substance of the body. Many of them are, however, but repetitions of one another; and there is by no means that *variety* of movement among them, which we meet with in Vertebrata.

Structure and Actions of Muscular Fibre.

578. Every muscle is formed by the union of a number of bundles, which are united together by means of areolar tissue, and are themselves composed of bundles still more minute, united in a similar manner. These, again, may be separated in the same way; and at last we come to the *primitive fibres* of which this tissue is composed. Each of these primitive fibres consists of a delicate membranous tube, enclosing a great number of *fibrillæ,* or extremely minute fibrils, which are not capable of

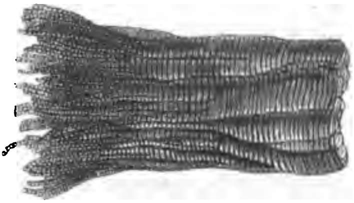

FIG. 202.—MUSCULAR FIBRE SEPARATING INTO FIBRILLÆ.

further division. Perfectly-formed muscular fibre exhibits a remarkable and very characteristic set of transverse bands or *striæ;* and, when it is separated into its fibrillæ, it is seen that this appearance is due to the peculiar markings which every fibril presents. These markings, consisting of alternate light and dark spaces, give to the fibril a beaded appearance; but this is only an optical deception, since it is really cylindrical in form. It is easy to see how the correspondence of the light and dark spaces respectively, throughout the whole bundle of the *fibril*, will give rise to the banded appearance which the *fibre* presents. The form and diameter of the fibres vary considerably, both in different tribes, and in different parts of the same animal. In the higher classes, its form usually approaches a cylinder; but the parts which press against one another are somewhat flattened, so that it is more or less prismatic. In Insects, on the other hand, the fibrillæ are arranged in flat bands, so that the fibre often consists but of a single layer of them. The diameter of the *fibrils* is nearly the same in all classes, seldom departing much from 1-10,000th of an inch; and the average distance of the dark striæ from each other is nearly the same.

579. Under the influence of certain exciting causes, or *stimuli*, muscular fibres suddenly and forcibly contract. Their two ends approach one another, and their striæ become closer; but they bulge out in the middle, to a corresponding degree. This causes a like change in the bundles which are made up of these fibres; and thus the whole muscle, when shortened by the drawing-together of its two ends, is greatly enlarged in diameter, especially towards its middle. Of this any one may convince himself, by bending his fore-arm upon the arm (as when the hand is brought to the mouth), and feeling the fleshy mass upon the front of the latter. The muscle, in fact, does not in the least degree change its own bulk in the act of contraction; for its enlargement in diameter is exactly equivalent to the shortening of the distance between its extremities.

580. It appears, however, that when an ordinary muscle is thrown into contraction, *all* its fibres do not contract together,

but only a small part of them. It seems to be a peculiar property of muscular fibre, however, that its contraction should be speedily followed by relaxation; and it appears that, whilst a continued contraction is taking place in the whole muscle, so that a constant force is exerted by it, there is a continual interchange in the action of the fibres by which this takes place,—those which have been shortened becoming slack, and being replaced (as it were) by others, which pass into the contracted state for a time, and then relax again, being succeeded by another set. Now as the ends of those fibres which are actually in a relaxed condition, are brought near together by the contraction of the rest, the fibre is thrown out of the straight line, and assumes a wavy or zig-zag form. It was supposed until lately, that this is the state of contraction; but it is now known to be otherwise. This peculiar arrangement gives place to the straight form, either when the fibre passes into the state of contraction, or when, by the relaxation of the whole muscle, its ends are separated again to their full extent.

581. Now the alternate contraction and relaxation, which is thus made to produce a continued contraction in ordinary muscles, elsewhere occasions a different effect. Thus in the heart, *all* the fibres of the ventricles seem to contract together, and all to relax together,—those of the auricles contracting whilst the others are relaxing, and *vice versa*;—and in this way the alternate contractions and dilatations of that most important organ are continually kept up. Again, in the muscular coat of the intestinal canal, we observe the contraction of each part to be almost immediately followed by its relaxation; but the peculiarity of its movement is, that the contraction is propagated on (as it were) to the succeeding part, which in its turn contracts and then relaxes, producing the same action in the part that follows it,—and so on along the whole canal. This *peristaltic motion* (§. 215) as it is called, is obviously adapted to propel the contents of the intestinal tube from one extremity of it to the other; just as the peculiar action of the heart is adapted to receive and propel the blood alternately; and as the mode of contraction of the ordinary muscles, enables them to keep up a continued strain for a great length of time.

582. The extremities of the muscles are usually attached to bones, which their contraction causes to move one upon the other. Of these attachments, one is usually called the origin, and the other the insertion,—the origin being in the part that is most fixed, and the insertion in that which moves upon it. Thus the muscle already spoken of as concerned in bending the elbow, has its origin at the shoulder, and its insertion in the bones of the fore-arm,—its general action being to move the latter, while the former is fixed or nearly so. But its attachment to the fore-arm may really become its origin, and its other attachment its insertion; for, when a person is hanging by his hands from a beam or cord, and raises his body by bending his elbows, the fore-arm is the fixed point, and the shoulder is moved upon it. In like manner, the muscular mass at the bottom of the back, having one attachment to the bones of the pelvis and another to the thigh-bone, serves to draw the latter backwards, when the former is made the fixed point, as when we rise up from the sitting posture; but it is also continually serving to keep the body upright upon the thighs, the latter being the fixed point, and brings it into this position when it has been bent forwards, as in stooping. Muscles are seldom *directly* attached to bones; but are united with them by means of the peculiar substance which is called *tendon*. Sometimes the tendon is long and round; this is the case with several of those that move the hand and fingers, which arise from the muscles forming the fleshy part of the fore-arm, and may be felt at the wrists as hard round cords. In other instances, however, the tendon is a broad flat band; of such we find several within the shell of the body and limbs of the Crab or Lobster, when we have removed the muscle or flesh.

583. The peculiar contractility of muscular fibre may be called into action by various causes. As in certain vegetable tissues (VEGET. PHYS. §. 420), contraction may be excited by a stimulus *directly* applied to the muscle itself. Thus, if the heart of an animal recently killed be touched with a pointed instrument, it will contract, and then dilate, as if performing its ordinary action; and this may be repeated several times. In the same manner, if the walls of the intestinal canal be pricked or

pinched, they will recommence and continue for a short time their peristaltic movement. And if any part of an ordinary muscle be irritated in the same manner, that particular bundle will contract; but the rest will not be affected. Now these actions are analogous to those performed by the Sensitive Plant, the Venus's Fly-trap, and many other plants, some part of whose tissues contracts in like manner when an irritation is applied to it, causing—it may be—extensive and important motions. It appears to be in this manner, that the contractions of the heart, and of the alimentary tube from the stomach to the rectum, are ordinarily excited in the living body. The contact of blood with the lining membrane of the heart stimulates its muscular walls to contraction, as long as they retain their perfect structure and properties, even though the connection of that organ with the nervous system has been completely cut off. But there must be some other cause for the continuance of its regular movements; for the heart of many cold-blooded animals will continue to contract and dilate, for many hours after it has been removed from the body, when it neither receives nor propels blood, and can have no influence from the nervous system. There is an instance on record, in which the heart of a sturgeon, which had been removed from the body and inflated with air, continued to beat, until the auricle had become so dry as to rustle during its movements. In the same manner, the peristaltic motions of the intestine continue to propel its contents for some time after the general death (§. 55) of the body; and may even take place when the whole tube is removed from it. It is interesting to remark, that in these two instances, in which the contractility of muscular fibre is called into action in the same manner as that of the contractile tissues of Plants, it is applied in both cases to the maintenance of the organic or vegetative functions; and it serves the purpose of placing them altogether beyond the control of the will, and of keeping up the necessary movements, even without our consciousness.

584. But the muscles of the trunk, limbs, &c., are not called into action in this manner; for, as just now stated, a stimulus applied to any one part of these does not excite contraction in

the whole muscle (as it does in the case of the heart), but only in the individual bundle of fibres irritated. These muscles are all of them supplied with nerves from the Cerebro-spinal system, or the nervous centres that correspond to them in Invertebrated animals;—and it is only by a stimulus transmitted to them along these trunks, that all the bundles of which the muscle is composed, can be called into action at once. The nervous trunks which enter the muscles divide into branches, which again subdivide into minute fibres; and these spread themselves throughout the muscle, forming loops, which return again to the trunks. The nerve-tubes pass among, and into, the bundles of muscular fibres; but in no instance do they enter the tubular sheaths of the latter.

585. When the trunk of a nerve supplying a muscle is irritated by pricking, pinching, &c., in the body of a living animal, or in one recently dead, the whole muscle is thrown into contraction; and this contraction is peculiarly strong, when a current of electricity is transmitted along the nerve. In cold-blooded animals, whose muscular fibre retains its vital properties for a much longer time after death than that of warm-blooded, this contraction may be excited by a very feeble current of electricity, in a limb which has been separated from the body for 24 hours or more; and it was owing, in fact, to this circumstance that the peculiar form of electricity which is now termed Galvanic or Voltaic, was discovered. The wife of Galvani, who was Professor of Medicine at Bologna, being about to prepare some soup from frogs, and having taken off their skins, laid them on a table in his study, near the conductor of an electrical machine, which had been recently charged; and she was much surprised, upon touching them with the scalpel (which must have received a spark from the machine) to observe the muscles of the frog strongly convulsed. Her husband, on being informed of the circumstance, repeated the experiment; and found that the muscles were called into action, by electricity communicated through the metallic substance, with which the limb was touched.

586. The experiment was repeated in various ways by Volta, who was Professor of Natural Philosophy at Pavia; and

he found that the effects were much stronger, when the connecting medium through which the electricity was sent, consisted of *two* metals instead of one; and from this circumstance he was led to the discovery, that electricity is *produced* by the contact of two different metals,—a discovery which has since been so fruitful in most important results. (See Treatise on ELECTRICITY.) The following simple experiment puts this in a striking point of view. If the skin of the legs of a Frog recently killed be removed, and the body be cut across, above the origin of the great (sciatic) nerve going to the legs,—if the spine and nerves be then enveloped in tin-foil, and the legs be laid upon a plate of silver or copper,—convulsive movements in the muscles will be excited, every time that the metals are made to touch each other, so as to complete the electric circuit.

587. Similar experiments have been tried with the Voltaic battery, upon the dead bodies of criminals recently executed. If one wire be placed upon the muscles which it is desired to call into action, and the other upon the part of the spine from which the nerves proceed, movements of every kind may be produced; and the application of electricity in this manner, so as to renew the motions of the diaphragm, is probably the best means of restoring vital activity, after it has been suspended by drowning, or suffocation (§. 338). No agent more effectually imitates the natural action of the nerves, in exciting the contractility of muscles, than Electricity thus transmitted along their trunks; and it has been hence supposed, by some philosophers, that electricity is the real agent by which the nerves act upon the muscles,—more especially since it is certain that, in those animals which generate large quantities of electricity, the nerves have a great share in this peculiar operation (§. 423). But there are many objections to such a view; and this very important one among the rest,—that electricity may be transmitted along a nervous trunk which has been compressed by a string tied tightly round it, whilst the passage of ordinary nervous power is as completely checked by this process, as if the nerve had been divided. We have already seen, too, that electricity, transmitted along the sensory nerves, excites the peculiar changes in the

brain, by which sensations are produced (§. 488); and thus it appears that, in their effects, as well as in their mode of action, there is more *analogy* between electricity and nervous agency, than there is between any other two powers of animated and inanimated nature.

588. The power, whatever be its nature, by which the Nerves act upon the Muscles in the living body, originates in the central organs, or ganglionic masses, of the nervous system, and is propagated from these, through the nervous fibres to the muscles,—in a mode precisely analogous to that in which the electric power, called forth by the action of an electrical machine or galvanic battery, is transmitted to any distance through conducting wires. If the conductor be divided, no action at the centre, however powerful, can produce any change at its extremities; and in this manner, by division of the nervous trunk, the muscle supplied by it is *palsied*. The muscle itself does not thereby lose its contractility; for it may still be made to contract, by a stimulus transmitted through the part of the trunk that remains attached to it,—as, for instance, by pricking or pinching the cut extremity, or by passing an electric current along it; but it is completely withdrawn from the dominion of the nervous centres, under which it previously was; and can neither be called into action by the will, by an emotion, or by a reflex impulse. The part of the trunk in connection with it soon loses its power of conveying irritations; and the muscle itself, being thrown into disuse, in time loses its contractility.

589. From this last fact it has been supposed, that the contractility of muscular fibre depends upon its connection with the nervous system, and is not an endowment peculiar to itself. But this idea is disproved by a number of circumstances. Thus the contractility of the heart and intestinal tube is exhibited, long after these parts have been separated from their nerves. The contractility of other muscles may be exhausted, by repeated excitement, so that even the stimulus of galvanism will not produce movement in them; and yet it may be recovered after the nervous trunks have been divided. And it has been ascertained that if the muscles be frequently exercised, as by the application

of galvanism once or twice a day, they will retain their contractility for any length of time. This exercise is further found to have the effect, of preventing the wasting-away of the muscles which otherwise takes place; and thus we see that the preservation of this peculiar property is dependent upon the due nutrition of the muscle, whilst the loss of the property results from its want of nutrition,—as we find to be the case in regard to other tissues. Further, the activity of the nutrition of muscles depends in great part upon the use that is made of them; and thus we find that any set of muscles in continual employment undergoes a great increase in size and vigour; whilst those that are disused, even though their nervous connections remain entire, lose their firmness and diminish in bulk, until, if the inaction be continued long enough, almost all trace of proper muscular substance disappears, and the contractility of the part is lost.

590. But a muscle may be *palsied* by some change taking place in the central organs, which shall prevent the nervous influence from being excited there. Thus by an effusion of blood in a certain part of the brain, the arm, leg, or the whole of one side may be paralysed to the influence of the *will*. But the muscles which are thus withdrawn from the power of the will, may yet be moved by an *emotional* or *instinctive* impulse, or by *reflex* actions; provided its connection with the parts of the nervous centres, in which these actions originate, be unimpaired (Chap. x.) Thus, a completely paralytic arm has been seen to be violently shaken, when the emotions of the patient were strongly excited by the approach of a friend. The muscles of the shoulder, in a case of complete paralysis of one side, were called into contraction in the reflex movement of yawning (§. 341). And the muscles of the legs, when their communication with the brain,—and consequently the control of the will over them,—has been completely cut off, have been made to act energetically when the feet were tickled, although the patient was not conscious either of the irritation or of the motion. When the muscles are thus aroused to occasional activity, their nutrition is not so much impaired, and their contractility does not depart nearly as completely, as when they are thrown into entire disuse, by dividing their nerves.

591. Muscles are commonly divided into *voluntary* and *involuntary*, according as they act in obedience to the will, or are not under its dominion. But this is not a correct division; since, whilst nearly all the muscles of the body are more or less under the control of the will, they may all at times have an involuntary action. The heart and the muscular coat of the alimentary canal, with the muscles concerned in swallowing and in one or two other actions of a similar character, are the only muscles which the will cannot either set in action, or control when in action. There are several muscles whose usual movements are of a reflex and, therefore, involuntary character; which are yet capable of being, to a certain extent, controlled and governed by the will. Such are the movements of respiration; which will continue to take place after the brain has been removed, and which go on regularly during the profoundest sleep, and the most complete withdrawal of the attention from them. In the Invertebrated animals, these motions are probably not influenced by the will; but in the air-breathing Vertebrata, they are placed in a certain degree under the dominion of the will, in order that they may be made to contribute to the production of the *vocal* actions of speaking, singing, &c., which are restricted to these classes. We can hold the breath for a certain time by a voluntary effort, or we can expel or draw it in more quickly than usual; but no voluntary effort can cause the breath to be held for more than a few moments; for the uneasiness which is then felt, and which is continually increasing, causes an involuntary action of the muscles, by which it is relieved. But again, there are other muscles, whose ordinary actions are voluntary; but which are occasionally made to act independently of the will, or even against its direction. Such are those which are excited by the emotions, as in laughing, crying, sobbing, &c. We may have the strongest desire to check these actions, owing to the unfitness of the time and place for their manifestation; and yet we may be unable to do so. And lastly, muscles, whose action is usually voluntary, may be occasionally called into powerful contraction, which the will cannot in the least degree control or prevent; this is the case in cramps, convulsions, &c., of various kinds.

592. All these facts are readily accounted for by the knowledge we now possess, of the different sources of muscular movement. It has been already shown (§. 464) that every motor trunk proceeding to a muscle, contains filaments that are derived from at least two different sources,—one of these the brain, and the other the spinal cord. Now those muscles which are chiefly supplied by the latter, and usually receive from it their stimulus to contraction (which is the case with those of respiration) will be more involuntary in their character than those, which are chiefly supplied from the brain, and which are less connected with the spinal cord,—as is the case with the muscles that move the limbs. And those muscles which are called into action by the emotions, probably receive a third set of fibres, from a part of the nervous centres different from either of the preceding; and the influence transmitted by these fibres may be so strong, as not to be capable of being resisted by others.

593. The vigorous action of the muscular structure is dependent upon several causes. In the first place, it requires (as we have already seen) an active nutrition of the muscles themselves. Firm, plump, and high-coloured muscles act with greater force than those which are pale and flabby, even though the size of the latter may be greater. Again, in all those animals whose activity is greatest, a constant supply of oxygen is requisite for muscular vigour. This is conveyed, in Birds and Mammalia, by the blood (§. 234); in Insects, on the other hand, it actually enters the muscular tissue, in the state of atmospheric air (§. 320). In Reptiles, again, the blood goes to the tissues very imperfectly oxygenated; and their movements are comparatively slow and feeble. But it is a remarkable circumstance, that in the dead bodies of the latter, or in parts separated from the living body, the property of contractility does not depart nearly so soon, as it does in similar parts of warm-blooded animals. By experiments on Mammalia it has been found, that the muscles of the trunk cannot be caused to contract by galvanism, for more than two or three hours after death; though the auricles of the heart retain their contractility for some hours later. The muscles of Birds (whose respiration

is more active, and whose temperature is higher) lose their contractility yet sooner; but those of Reptiles sometimes retain the power of contracting for several days. When venous or imperfectly-aerated blood is made to circulate through the vessels of warm-blooded animals, it acts like a poison upon them, diminishing or even destroying their contractility.*

594. Further, the energy of muscular contraction depends in great degree upon the power of the stimulus which is transmitted to it through the nervous system. We often have the opportunity of observing this, in the case of persons who are under the excitement of violent passion or of insanity; a delicate female is frequently a match for three or four strong men, and can even break cords and bands that would hold the most powerful man in his ordinary state. The strength in such circumstances seems almost preternatural; but it is not greater than that which we see manifested in convulsive actions, where the movements depend only upon the spinal cord. Thus a slender girl affected with spasmodic affection of the muscles of the spine, which threw the back into an arch, of which the head and heels were the two resting-points, has been known to raise a weight of 900lbs. laid on the abdomen, with the absurd intention of straightening the body.

595. The sense of fatigue, which comes on after prolonged muscular exertion, is really dependent upon a change in the brain, though usually referred by us to the muscles that have been exercised. For it is felt after *voluntary* motions only; and the very same muscles may be kept in *reflex* action for a much longer time, without any fatigue being experienced. Thus, we never feel tired of breathing; and yet a forced voluntary action of the muscles of respiration soon causes fatigue. The voluntary use of the muscles of our limbs, in walking or running, soon causes weariness; but similar muscles are used in Birds and Insects, for very prolonged flights, without apparent fatigue;

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* Other substances do this with even greater rapidity; thus a strong solution of nitrate of potass (nitre) injected into the blood-vessels, and conveyed by them to the heart, causes the immediate cessation of its action—the poison finding its way, through its own vessels, into the capillaries of the muscular structure.

and as we find that the actions of flight may be performed, after the brain, or the ganglia that correspond to it in Insects, have been removed (§§. 444, 465), we may regard them as of a reflex character; and the absence of fatigue is thus accounted for.

596. The *energy* of muscular contraction appears to be greater in Insects, in proportion to their size, than it is in any other animals. Thus a Flea has been known to leap sixty times its own length, and to move as many times its own weight. The short-limbed Beetles that inhabit the ground have an enormous power, which is manifested both in their movement of heavy weights, and in the resistance they overcome with their jaws. Thus the Dung or Shard-borne Beetle can support uninjured, and even elevate, a weight equal to at least 500 times that of its body. And the Stag-Beetle has been known to gnaw a hole of an inch diameter, in the side of an iron canister in which it had been confined. The *rapidity* of their movements is also most extraordinarily great, and is especially seen in the vibrations of their wings. It would be impossible to form an estimate of the time occupied by these, were it not for the musical tone they produce; and it may be calculated from these (upon principles which will be explained in the Treatise on SOUND) that the wings of many Insects strike the air *several hundred* times,—and those of some of the smaller Insects *many thousand* times,—in a second of time.

Of the Apparatus of Movement in general.

597. Muscular contraction performs an important part in nearly every one of the functions, of which we have already treated. Thus the reception of the food, and its propulsion along the alimentary canal, forming part of the function of Digestion, are accomplished through its means. The Circulation of the blood, again, depends mainly on the agency of a contractile organ, the heart. The Respiration cannot be kept up, in the higher animals at least, without the aid of certain movements, which are accomplished by the muscles. With the processes of Nutrition and Secretion, it is not so closely connected; but the latter is dependent upon it so far as this, that its products are carried out of the body by the aid of muscular

contraction. And even in Sensation, the peculiar endowment of muscular tissue comes into use; by giving to the organs of sense those movements, which enable them to take a wider range, and to apply themselves most perfectly to the objects before them. But we have now to study its applications in those general and partial movements of the body, on which depend the *locomotion* (or change of place) of animals, their attitudes, and a number of other important actions, entirely of a mechanical nature. The organs by which these are effected, may be conveniently divided into the *active* and *passive*. The *active* are those which have peculiar vital powers within themselves, and which exert these by giving motion to other parts. To this class, therefore, we refer the muscles, whose peculiar endowments have been just considered. The *passive* organs, on the other hand, are those which perform no action of themselves, which have no power but that of yielding a simply mechanical support, and which consequently perform no movement but such as they are made to do by the muscles. Of this kind are the hard parts which form the skeleton or solid framework of the body, whether this be internal or external.

598. In the lower tribes of animals, the muscles are all inserted in the soft and flexible membrane which covers the body; and it is by acting upon it, that they can change the form of the body, in such a manner as to cause it to move, either altogether or in part. This is the case, for example, in the Leech, Earthworm, and other Annelida; which are furnished with two sets of muscular fibres, one running along the body, and the other passing round it in rings. By the contraction of the former, the two ends are drawn together, so that the body is shortened; whilst by that of the latter, its diameter is lessened, so that it is necessarily lengthened. By these two movements, which take place alternately, the progression of the animal is accomplished; and by varying the contractions of one part or another, almost any form and direction can be given to the soft and flexible body.

599. But in the higher animals, we find the apparatus of movement to consist, not only of muscles, but also of a framework of solid pieces; which serves to augment the precision, the force,

and the extent of the movements; whilst, at the same time, it determines the general form of the body, and protects the viscera against external forces. This solid framework, or *skeleton*, to which the muscles are attached, may be, as we have seen, either internal or external. In the Vertebrated classes, the hard skeleton is internal; in the Articulated series it is external; in the Mollusca it can scarcely be said to exist, since no muscles are attached to the shell, save those that serve to attach the animal to it, or to draw together its valves; and in the Radiata, its position is variable, being sometimes external, as in the Echinodermata, and sometimes internal, as in the stony Corals.

600. The peculiar structure of some of these parts has been already described. It has been stated that the *bones* of Vertebrata differ from all other substances of a similar hardness, in being penetrated by *blood-vessels*; but it is not the only substance in which *tubes* exist; for a system of tubes resembling those of teeth, or those which radiate from the minute cavities in bone (§. 48), is to be found in the shells of some Mollusca and Crustacea, and even in the stony Corals, as also in the bony scales of certain Fishes. All these parts are formed by the consolidation of living animal tissue, by deposits of carbonate of lime or other mineral matter; and the difference between them consists mainly, in the nature of the tissue thus consolidated. Thus in some shells, it is previously cellular, constituting a sort of epithelium; in others it is simply membranous. In the Polypifera it seems to be a very delicate cellular tissue, resembling that of which the soft bodies of the animals are composed. And in the Echinodermata, the animal substance which remains after the lime has been dissolved away by acid, has rather the characters of areolar tissue,—consisting, not of cells, but of plates and shreds of membrane, interwoven into a structure that contains numerous cavities communicating with each other.

601. The different portions of the skeleton are *articulated*, or united by joints to one another, in such a manner, that they can move with greater or less freedom. This we see both in the Vertebrated and Articulated classes. In the latter, the joints are for the most part very simple in their construction. The

different rings or pieces are held together by a flexible membrane passing from one to the other; this seems to be little else than a portion of the integument that originally covered the body, which has remained unconsolidated, whilst the rest has been hardened. And sometimes they are made to adhere to each other by a kind of *soldering;* so as to be altogether immovable. But in the internal skeletons of the Vertebrata, we find a more complex mode of union, fitted to afford scope for the greater variety of motions which their parts perform. Here, too, we find some parts immovably united to each other, where support and protection alone are required. These immovable articulations, of which there are several kinds, will be first considered.

602. All the bones of the head and face (with the exception of the lower jaw), in Man and the higher Vertebrata, have their edges in immediate contact with each other; so that they hold together in the dry skull, as well as during life. Those bones of the skull, which inclose and protect the brain, are very firmly united by what are termed *sutures;*[*] which are mostly formed by the interlocking of the jagged edges of one bone, into corresponding notches of the adjoining one; though in some, this kind of union is incomplete; and in others it is replaced by a *bevelling* of the edges that are in contact, or by the reception of a ridge of one bone into a groove in the other. So firmly are the bones united in this manner, that it is difficult to separate them without breaking away some of their projecting parts; and in the skulls of old persons, the sutures are almost obliterated by the complete union between the adjacent bones. In the infant, on the other hand, the bones of the skull are only united to each other by a membranous substance; and there is a point at the top of the head, which is not even covered by a bony layer for some time after birth. It is only as the age advances, and the ossification becomes more complete (§. 51), that the firm bony union is effected.

603. In several other articulations, the bones do not come into direct contact with each other, but are united by an intervening layer of cartilage, and also by ligaments and other fibrous

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[*] From the Latin, *sutura*, a seam.

membranes encircling the articulations. The adjacent surfaces of the bones are flat, and have a slight gliding movement over one another; but the extent of motion permitted is very small. This kind of articulation exists between the bodies of the vertebræ of Man and the higher Vertebrata, between the bones of the pelvis, and some other parts.

604. The proper movable articulations, by which the limbs are connected with the trunk, and their different divisions to each other, are those to which we commonly give the name of *joints*. In these, the surfaces of the adjacent bones are not united in any other way, than by the ligaments and muscles which surround them; and they have a free gliding movement over each other. They are covered, it is true, by cartilage; this, however, does not pass from one bone to the other, as in the previous case; but forms a thin layer over the end of each, and presents a very smooth surface, which greatly facilitates the motion of the joint. These surfaces are kept moist by a fluid termed *synovia;* this is secreted by a serous membrane which covers them, and which forms a closed capsule or bag, much resembling that of the pericardium (§. 256). The beautiful smoothness of the surfaces of the joints, and the manner in which the bones are held together by the muscles and ligaments, is well seen by examining the knuckle-joint at the lower end of a leg of mutton (before being cooked), and the other joint which connects it with the bones at the top. These two joints are examples of the two principal varieties of freely-movable articulations,—the *hinge*-joint, and the *ball-and socket* joint. In the first of these, the surfaces of the bones are so formed, that the movement, though free as regards its extent, is very limited in its direction, being in fact restricted to a backward and forward action in the same line, just like that given by a common hinge. In the second, the end of one bone is formed into a rounded head or ball; and this is received into a corresponding socket or cup in the other, the edge of which is usually deepened by cartilage; in this manner, the bone which carries the ball is enabled to move upon the other in any direction, unless checked in other ways. Of the hinge-joint we have examples in the elbow, the

knee, and the joints of the fingers and toes. Of the perfect ball-and-socket joint, we have in Man only two examples,—the shoulder, and the hip. In the former, the socket is much shallower than in the latter; and the motions of the arm are consequently more extensive than those of the thigh. Both, however, are unchecked in regard to their direction, except when the limb is brought against the body or against its fellow. The wrist and the ankle-joint are of an intermediate character; the former more resembling the ball-and-socket, and the latter the hinge-joint.

605. All these joints are more or less subject to *dislocation*, by violence of different kinds. This takes place by the slipping away from each other of the two surfaces, which ought to be in contact. Thus the head of the humerus (or arm-bone) may slip over the edge of its socket, so as to lie entirely on the outside of it; and this, in consequence of the shallowness of the cup, happens not unfrequently. The head of the thigh-bone, also, may slip out of *its* socket; but this accident is more rare, on account of the deepness of its cup. The elbow and knee-joints, as also those of the wrists, ankle, fingers, and toes, may be dislocated by the slipping of one surface on the other, either forwards, backwards, to one side or to the other. One of the most common dislocations is that of the thumb, the lowest articulation of which has rather the character of the ball-and-socket (with a very shallow cup), than of the hinge-joint. But in proportion to the liability of any joint to dislocation, is usually the ease with which it may be brought into place again.

606. The action of any muscle in producing a change in the position of a movable bone on which it acts, is determined in the first place, by the nature of the movement of which the bone is capable; and in the second, by the direction in which the power of the muscle is applied to it. Having now considered the former of these conditions, we proceed to the latter. The contraction of a straight muscle which is attached to a fixed point at one end, and to a movable point at the other, will obviously tend to draw the latter towards the former. Thus, the muscles which bend the fingers lie in the palm of the hand, and

on the corresponding side of the fore-arm; whilst those that straighten the fingers are situated on the opposite side. But we often find that the direction of a muscle's action is changed, by the passing of its tendon through a pulley-like groove or loop; so that it draws the movable bone in a direction different from that of its fixed attachment. This is the case, for example, with some of the muscles that bend the toes; these being situated in the calf of the leg, would draw the toes upwards, were it not that their tendons are carried beneath the bones of the heel, working in smooth pulley-like channels hollowed out in them; hence, when the muscle contracts, the tendons draw the ends of the toes towards the heel, and thus bend them.

607. We generally find that even movements of a simple character are performed by the combined action of several muscles; of which some may be considered as the principal, and others as assistants. Those which are principals in one movement may become assistants in another; and *vice versâ*. Thus, if we wish to bend the wrist directly downwards upon the fore-arm, we put in action, not only certain muscles whose tendency would be to produce this movement, but others which, acting by themselves, would produce a different motion. One of these would draw the wrist towards the thumb-side of the fore-arm; and the other towards the little-finger-side; and they become the principal muscles in these movements respectively: but when they act together, their several tendencies to draw the wrist to the opposite sides counterbalance one another, and they simply assist the principal muscles in bending the wrist downwards upon the fore-arm.

608. Almost every muscle has its *antagonist*, which performs an action precisely opposite to its own. Thus by one set of muscles, termed *flexors*, the joints are bent; by a contrary set, the *extensors*, they are straightened. One set of muscles draws the arm or leg away from the central line of the body; another draws the limbs inwards. One set, again, closes the jaws; and another opens it. In short, we shall find that probably every muscle in the human body has its antagonist in another muscle, or in some part of it. But we find an economy of muscular

substance in some of the lower animals, where parts are to be usually kept in a particular position, and this is only to be changed occasionally and for a short time. Thus the valves of the Conchiferous Mollusca (§. 124) are kept apart, not by a muscle, but by an elastic ligament; but they are closed, when the animal is alarmed and wishes to protect itself, by muscular action. In the same manner, the sharp claws of the Cat tribe are usually drawn in by an elastic ligament, that their points may not be worn away by rubbing against the ground; whilst they are forced outwards by the action of a muscle provided for the purpose, when the animal desires to fasten them into its prey.

609. We commonly find that, in order to preserve the necessary form of the animal body, muscles are applied at a great mechanical disadvantage, as regards the exercise of their *power;* that is, a much larger force is employed, than would suffice, if differently applied, to overcome the resistance. But we generally find that, in this as in other forms of lever action, what is lost in power is gained in time; and thus a very slight change in the length of a muscle is sufficient to produce a considerable movement.

610. The first source of disadvantage results from the *direction* in which the muscle is attached to the bone. This is rarely at right angles to it; and consequently a considerable part of the power is lost (see MECHAN. PHILOS., §. 299). Thus if the muscle m (Fig. 203), whose force we shall suppose equal to 10, is fixed at right angles to the bone l, whose extremity a is movable upon the point of support r; its force of contraction will be most advantageously applied to overcome the resistance, and will draw the bone from the position $a\ b$ into the direction $a\ c$, making it traverse a space which we shall also represent by 10. But if this muscle act obliquely on the bone, in the direction of the line $n\ b$ for example, it will be quite otherwise; for it will then tend to draw the bone in the direction $b\ n$, and consequently to make it

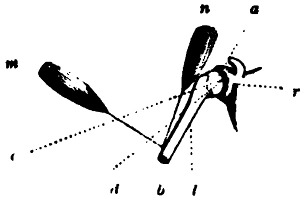

FIG. 203.

approach the articular surface *r*. But as this bears upon an immovable socket, and as the bone can move in no other way than by turning upon the point *r*, as upon a pivot, the contraction of the muscle to the same amount as before will carry the bone no further than into the direction *a d;* three quarters of the force employed will thus be lost, and the resulting effect will be no more than one-fourth of that, which the same power, applied perpendicularly to the bone, would have produced.

611. Now in the animal body, we usually find that the muscles are inserted so obliquely, that their power is applied at a great disadvantage; but this disadvantage is rendered much less than it would have otherwise been, by a very simple contrivance,—the very enlargement of the bones at the joints, which is necessary to give them the required extent of surface for working over each other. Thus, let *r* and *o* (Fig. 204) be two bones connected by a joint; and let the muscle *m*, which moves the lower bone upon the upper, be attached to the former at *i*. Now as this muscle acts almost precisely in the line of the bones themselves, almost all its power will be expended in drawing the lower bone against the upper. But by the enlargement of the ends of the bones, as seen in Fig. 205, the direction of the tendon of the muscle *m* is so changed, near its insertion *i*, that the contraction of the muscle will cause the lower bone to turn upon the upper one with comparatively little loss of power. In the Knee we find a still greater change of direction effected, by the interposition of a movable bone, the *patella* or *knee-pan*, in the substance of the tendon.

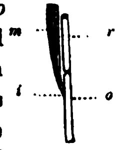

FIG. 204.

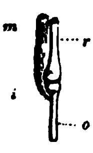

FIG. 205.

612. But the advantage or disadvantage with which the muscles act upon the bones, depends in great degree upon the distance of their point of attachment, from that of the point of support on which the bone moves, and from the point at which the resistance is applied. Every bone acted on by muscles may be regarded as a *lever*, having its fulcrum or point of support in the joint, its *power* where the muscle is attached to it, and its *weight* where the resistance is to be overcome; and the distances

of the fulcrum from the power and the weight respectively, are termed the two arms of the lever. Now on the mechanical principles, fully explained elsewhere, (Mechan. Philos., §. 287,) the relative length of these two arms governs the force which is necessary to overcome a given resistance. Thus in the Steelyard (Fig. 206), the beam is divided into two arms of unequal length at the point of support or fulcrum a; at the end of the short arm, r, hangs the body whose downward pressure we wish to determine; and on the other, p, there slides a weight, which will balance a greater or less amount of pressure at the opposite extremity, r, according as it is made to hang from a point which is more distant from the fulcrum or nearer to it,—that is, according as the length of the power-arm of the lever is increased or diminished, that of the weight-arm remaining the same.

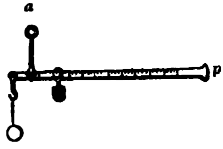

Fig. 206.

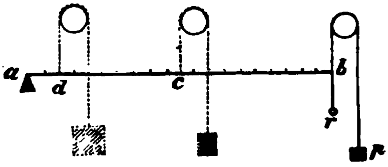

Fig. 207.

613. Now in order that there may be an equilibrium, or balancing between the power and the weight, it is necessary that they should be inversely proportional to the lengths of their respective arms; that is, the power multiplied by the length of its arm, should be always equal to the weight multiplied by the length of *its* arm. Thus, to balance a certain resistance, r, equal to 10, and applied at the end of a lever, a b, whose length we shall call 20, it is necessary that a force, p, applied at the same point, and consequently at the same distance from the fulcrum, a, should also be equal to 10; but, if the power be applied at the point, c, which is at only half the distance from the fulcrum, a, it must be doubled in amount, or equal to 20,—since it must be sufficient, when multiplied by its distance, 10, from the fulcrum to make 200, which is the product of the resistance, 10, and its distance from the fulcrum, 20; and in like manner, if the power

be applied at *d*, where its distance from the fulcrum is only 2, its amount must be 100, in order that its product with the distance at which it is applied may be equal to 200. Hence when a muscle is applied near the fulcrum, while the resistance is at a distance from it, its force must be proportionably greater.

614. But this arrangement greatly increases the rapidity of the motion, which is the consequence of the muscular action. For let us suppose that the muscle *p* (Fig. 208), acts upon the lever, *a r*, in such a manner that its point of insertion, *c*, traverses a space equal to 5 in one second; the extremity, *r*, of the lever will traverse a space equal to 25 in the same time, its distance from the fulcrum, *a*, being five times as great as that of the point, *c*, from the fulcrum. Hence although, to raise a given weight at *r*, a power more than five times its amount must be applied at *c*, that power will raise the weight through a space five times as great as that, through which itself passes in the same time. Thus what is lost in power is gained in time; and the shortening of a muscle, small in amount, but effected with sufficient power, causes the raising of a weight through a considerable space.

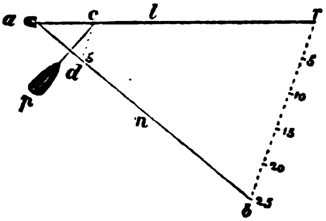

FIG. 208.

615. We shall find that this is the case in regard to most of

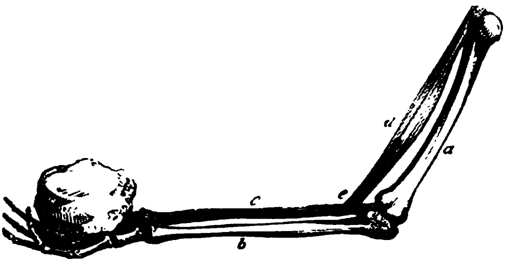

FIG. 209.

the muscular actions in the animal economy. Thus the fore-arm is bent upon the arm by a muscle, *d*, which arises from the top of the latter, and which is inserted at *e*, at a short distance from the elbow-joint. Hence its contraction to a very slight extent will raise the hand through a considerable space; but a proportional increase in its power will be required, to overcome any resisting force in the hand. The arm is straightened again, by an antagonist muscle, which lies on the back of the arm, and which is attached to a short projection made by one of the bones of the fore-arm *behind* the elbow. This muscle also acts at a similar disadvantage in regard to power, and advantage in point of time; in consequence of its point of attachment being so near to the fulcrum.

Description of the Motor Apparatus of Man.

616. Before entering upon the examination of the various movements of the lower animals, and of the means by which these are effected, it will be useful to acquire a general knowledge of the structure of the Human Skeleton, and of the uses of its several parts. The skeleton, which is formed by the union of 200 bones, is divided, like the body, into head, trunk, and members. The bones of these parts will now be separately described.

617. The *Head* is composed of two parts, the cranium or skull, and the face. The cranium is a bony case, of oval form, occupying the upper and back part of the head, and serving for the protection of the brain, which is lodged in its cavity. Its walls are made up of eight bones: the frontal, *f*, in the region of the forehead; the two parietal bones, *p*, which occupy the top and sides of the skull; the two temporal bones, *t*, which form the walls of the temporal region; the occipital bone, *o*, at the back of the head; and the sphenoid, *s*, and the ethmoid, which assist in forming the floor of the cavity. These bones are firmly united

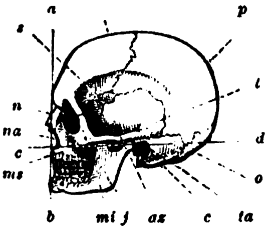

FIG. 210.—HUMAN SKULL: *f*, frontal bone; *p*, parietal; *t*, temporal; *o*, occipital; *n*, nasal; *ms*, superior maxillary; *j*, malar or cheek bone; *mi*, inferior maxilla; *na*, anterior opening of the nose; *ta*, auditory aperture: *az*, zygomatic arch; *a*, *b*, *c*, *d*, lines indicating the facial angle.

to each other by sutures, the character of which varies in different parts of the cranium, so that they are the better able to resist external violence. Thus a blow upon the top of the arch formed by the parietal bones, will tend to separate them from each other and from the frontal bone, and to force asunder their lower borders. Both these effects are resisted, by the peculiarity of the suture which unites different parts of the parietal bone to its neighbours. For at the top of the skull, the bones are firmly held together by the interlocking of the projections of each; whilst the lower edge of the parietal bone is prevented from being driven outwards by the overlapping edge of the temporal bones, which form, as it were, a buttress to the arch. This same contrivance prevents the temporal bone from being driven inwards, by a blow on the side of the head, as it might have otherwise been.

618. In the base or floor of the cavity of the cranium, are seen a number of apertures, which serve for the passage of the blood-vessels that supply the brain, and of the nerves that issue from it. One of these apertures, much larger than the rest, and situated in the occipital bone, serves for the passage of the spinal cord; and on each side of this aperture, there is a large bony projection from the under surface, termed the *condyle*, by which the skull rests upon the vertebral column, and is enabled to move forwards or backwards upon it. The head is nearly balanced upon this pivot; nevertheless, the portion situated in front of the joint is more heavy than that which is situated behind it, and is, in consequence, not altogether counterpoised by the latter. Hence the muscles, which, arising from the back and being attached to the occipital bone, tend to draw the head backwards, and thus to keep it upright, are more numerous and powerful than those, which are situated in front of the vertebral column, and tend to draw the head downwards and forwards; and when the former are relaxed, as in a person sleeping upright, the head has a tendency to fall forwards upon the chest. In no other animal is this joint situated so far forwards as in Man. As we descend the scale, we find it nearer and nearer to the back of the skull; and consequently the whole weight of the head bears, not

directly upon the spine, but upon the muscles and ligaments by which it is attached to the vertebral column.

619. On each side of the base of the cranium, we observe a large rounded projection, termed the mastoid. To this projection (which we feel behind the lower part of the ear) is attached on either side a powerful muscle, which passes downwards and towards the central line; so that the two muscles nearly meet at the bottom of the neck, where they are attached to the upper edge of the breast-bone. These muscles acting together, serve to draw the head forwards; but either of them acting separately will turn it to one side or the other. In front of these two projections of the skull, we notice the opening of the external ear, *t a;* which, like the different chambers of the internal ear, is excavated in a portion of the temporal bone, which is termed *petrous*, from its very dense and stony character.

620. The *face* is formed by the union of fourteen bones; and presents five large cavities, which serve for the lodgment and protection of the organs of sight, smell, and taste. All the bones of the face, with the exception of the lower jaw, are completely immovable, and are firmly united to each other and to the bones of the cranium (§. 617). The two principal are the *superior maxillary* (*m s*, Fig. 210), which form nearly the whole of the upper jaw, and which are connected with the frontal bone, in such a manner as to contribute to the formation of the orbital cavities in which the eye is lodged, and of the nasal cavities which form the interior of the nose; they also constitute the front of the roof of the mouth; on the sides of the face, they articulate with the malar or *cheek*-bones, *j;* and behind with the palate-bones, which form the back part of the roof of the mouth. These, in their turn, are united to the sphenoid.

621. The orbits, as we have already seen (§. 538), are two deep cavities, of a conical form,—the base of the cone being directed forwards, and the apex, or point of it, backwards; the roof of these cavities is formed by a portion of the frontal bone, and their floor chiefly by the superior maxillary. Their inside wall is formed by the ethmoid bone, and by the small bone termed the lachrymal, in which is the canal for the passage of

the tears into the nose (§. 540); and the outside wall is composed of part of the cheek-bone, and of a portion of the sphenoid, —the latter also bounding the cavity at its deepest part, and containing the apertures which serve for the passage of the optic and other nerves that enter the orbit from the cranium. In the roof of the orbit, on its outer side, there is a broad shallow pit or depression, in which the lachrymal gland is lodged.

622. The greater part of the nose is formed by cartilages; so that, in the bony skull, the anterior opening of the nasal cavity (*n a*, Fig. 210) is very large; and the bony portion of the nose, formed by the two small bones, termed *nasal* (*n*), projects but slightly. The nasal cavity, divided in the middle by a vertical partition, into two *fossæ*, or excavations, is very extensive; at the upper part, it is hollowed out in the ethmoid bone, the whole interior of which is made up of large cells; its floor is formed by the arch of the palate, which separates it from the mouth; behind it extends as far as the back of the mouth, and communicates with the pharynx by two apertures termed the posterior nares (Fig. 189, *c*). The partition between the fossæ is formed at the upper part by a plate that projects downwards from the ethmoid bone, and at the lower by a distinct bone called the *vomer* (or ploughshare) from its peculiar form; to the front edge of this last is attached a cartilage, which continues the partition forwards into the soft projecting portion of the nose. It is through the thin horizontal plate of the ethmoid bone, which separates the nasal cavity from that of the skull, that the olfactory nerves make their way out from the former into the latter; they descend in numerous branches, for the passage of which through the roof of the nose, this plate is perforated by a number of small apertures, which give it a sieve-like aspect; whence it is called the *cribriform** plate of the ethmoid. The cavity of the nose is further extended, by its connection with the *sinuses* or excavations that exist in the lower part of the frontal bone (where they sometimes cause a considerable projection above the eyes), in the superior maxillary bones, and in the

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* From the Latin, *cribrum*, a sieve.

sphenoid (see Fig. 189). The surface of the mucous membrane which lines it, and on which its nerves are distributed (§. 506), is also extended, by being carried over a set of bones, termed spongy bones, which hang, as it were, from the side walls of the cavity.

623. It is in the superior maxillary bone, that all the teeth of the upper jaw are implanted in Man; but in the infant, this bone is composed of several pieces; and one of these pieces, termed the *intermaxillary* bone, (*im*, Fig. 211,) remains permanently separate in most of the lower animals. The lower jaw of adult Man, also, is composed but of a single piece; though this is divided in the infant on the central line, and the two halves remain separate in many of the lower animals. This bone has a general resemblance, in form, to a horse-shoe with its extremities turned up considerably. It is articulated with the temporal bones by a *condyle* or projecting head, with which each of these extremities is furnished; and this head is received into what is termed the *glenoid*[*] cavity on the under side of the temporal bone. In front of the condyle is another projection, or *process*, termed the coronoid, (*a*, Fig. 104,) which serves for the attachment of one of the principal muscles that raise the Jaw. These muscles are all attached near the *angle* of the jaw (or the point at which it bends upwards), and they consequently act at a small distance from its fulcrum, whilst the resistance is applied at the furthest point (§. 189). We are

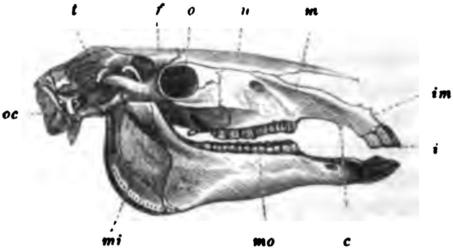

FIG. 211.—SKULL OF HORSE; *oc*, occipital bone; *t*, temporal; *f*, frontal; *n*, nasal; *m*, superior maxillary; *im*, intermaxillary; *mi*, inferior maxillary; *o*, orbit; *i*, incisor teeth; *c*, canines; *mo*, molars.

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[*] The term *condyle* is applied to most of the projecting surfaces of articulation, in different parts of the body; and the term *glenoid* to the cavities into which these are received.

continually reminded of the loss of mechanical power which results from this, by our inability to exercise the same force with our front teeth, that we can employ with the back. Thus, when we wish to crack a nut, or to crush any hard substance between the teeth, we almost instinctively carry it to the back of the jaws, so as to be nearer the joint, and thus to receive more of the power of the muscle.

624. The general arrangement of the chief muscles of the face is seen in Fig. 212. The largest is the *temporal* muscle, *t*, the fibres of which arise from an extensive surface of the parietal and temporal bones, and then converge or approach each other, passing under the bony arch or *zygoma*, *z* (which is partly formed by a process from the temporal bone, and partly by the malar or cheek bone), to be attached to the coronoid process of the lower jaw. This muscle is of extraordinary power in those beasts of prey, which lift and drag heavy carcases in their jaws; and in those which (like the Hyæna) obtain their support by crushing the bones which others have left. It is assisted by the *masseter* muscle, *m*, which passes from the zygomatic arch and cheek-bone, to the angle of the lower jaw; and also by other muscles. Besides these, the figure shows the ring-like muscle or sphincter, *o*, which surrounds the opening of the eye, and serves by its contraction to close the lids; and also the similar muscle, *b*,*b*, which surrounds the mouth, and draws together the lips. The antagonists to these are several small muscles, which form the fleshy part of the face, and produce the various changes by which its *expression* is given. These muscles are more numerous in Man and the Monkey tribe than in any other animals.

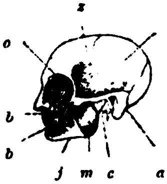

FIG. 212.

625. Besides the 22 bones of which the skull is properly composed, we may reckon as belonging to it the four small bones which form part of the apparatus of hearing (§. 516); and also the *hyoid* bone, which lies at the root of the tongue and at the top of the larynx (Fig. 105). This last bone in Man and the Mammalia generally, is connected with other parts of

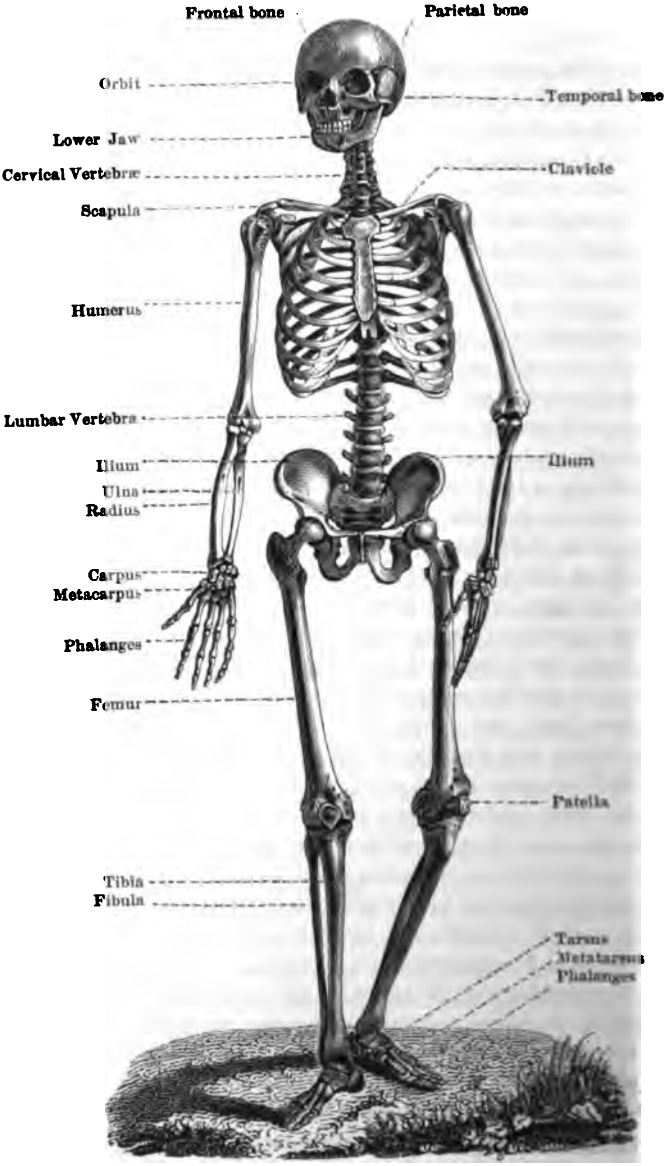

FIG. 213.—SKELETON OF MAN.

the skeleton, only by ligaments and muscles; but in Birds it is connected with the temporal bone on each side, by a set of bony pieces jointed together, like links in a chain.

626. The most important part of the *Trunk*, and even of the whole skeleton,—that which serves to sustain the rest, and which varies the least in the different classes of Vertebrated animals,—is the *spinal* or *vertebral column*. The general conformation of this has been already described (§. 64). In Man it consists of 33 vertebræ, which are arranged into five divisions;—I. The *cervical* vertebræ, *c*, or vertebræ of the neck, of which there are 7; II. The *dorsal* vertebræ, *d*, or vertebræ of the back, of which there are 12;—III. The *lumbar* vertebræ, *l*, or vertebræ of the loins, of which there are 5;—IV. The *sacral* vertebræ, *s*, of which also there are 5;—and V. The *coccygeal* vertebræ, *co*, of which there are 4. All these vertebræ are separate at the time of birth; but the 5 sacral vertebræ are soon afterwards united into one piece, forming the bone which is termed the *sacrum;* and the coccygeal vertebræ are also commonly united into one piece, the *coccyx*, which is not unfrequently united in old age to the sacrum. In old persons, too, it is not uncommon for the lumbar vertebræ to be united together, by bony matter deposited in their cartilages and ligaments.

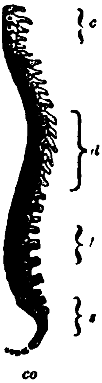

FIG. 214.
VERTEBRAL COLUMN.

627. The *dorsal* vertebræ are distinguished from the cervical and lumbar, as being those to which the ribs are attached. It is remarkable that the number of the cervical vertebræ should be the same in all the Mammalia; the long-necked Giraffe having only 7; and the Whale, whose head seems to be joined to its body without the intervention of any neck, also having 7 cervical vertebræ, although they are almost as thin as a sheet of paper. It is owing to the small number of joints in its neck, that the movements of the head of the Giraffe are far less graceful than those of the Swan and other long-necked Birds, in whom the number of cervical vertebræ is much greater. The

following table shows the number of vertebræ in animals of different groups.

Mammalia.	Cervical.	Dorsal.	Lumbar.	Sacral.	Coccygeal.	Total.
Man . . .	7	12	5	5	4	33
Long-tailed Monkey .	7	12	7	3	31	60
Lion	7	13	7	3	26	56
Long-tailed Opossum .	7	16	6	2	36	64
Long-tailed Ant-Eater.	7	16	3	6	40	72
Elephant . .	7	20	3	4	27	61
Giraffe	7	14	5	4	18	48
Whale . . .	7	15	9	1	27	59
Birds.						
Vulture . . .	15	7	—	13	6	41
Swallow . . .	13	7	—	10	7	37
Turkey . . .	14	7	—	15	6	42
Ostrich . . .	18	9	—	19	9	55
Crane	17	10	—	15	6	48
Swan . . .	23	11	—	16	8	58
Reptiles.						
Tortoise . . .	9	10	—	3	20	42
Monitor (Lizard) .	6	21	2	2	115	146
Python (Boa) . .	—	320	—	—	102	422
Rattle-Snake . .	—	171	—	—	36	207
Land Salamander . .	1	14	—	1	26	44
Axolote . . .	2	18	—	—	42	42
Fishes.						
Perch . . .	—	21	—	—	21	42
Mackerel . . .	—	15	—	—	16	31
Trichiurus . . .	—	60	—	—	100	160
Salmon . . .	—	34	—	—	22	56
Cod	—	19	—	—	34	53
Conger Eel . .	—	60	—	—	102	162
Electric Eel . . .	—	—	—	—	—	236
Shark . . .	—	95	—	—	270	365

We see from the above table, that it is by the multiplication of the coccygeal vertebræ, that the tail is prolonged in those animals which possess it. In fact, it is only in Man, and in those of the Ape tribe which approach nearest to him, that the number is as low as 4.

628. It has been already noticed (§. 64) that the essential character of the *vertebræ* consists in being perforated by an aper-

ture (Fig. 215), which, when several vertebræ are united together, forms a continuous tube or canal for the lodgment of the spinal cord. This character is usually lost, however, in the coccygeal vertebræ; which are so much contracted and simplified, as to contain no aperture. The purpose of the division of the spinal column into so large a number of separate bones, is obviously to allow of considerable freedom of motion, by a slight change of place in the individual parts; whilst any sudden bend, which would be injurious to the spinal cord, is avoided. Each vertebra consists of a solid *body* (*a*), which is situated in front of the spinal canal in Man, but below it in animals whose back has a horizontal position, and which serves to give solidity to the structure, —and of *processes* or projections (*b* and *c*), that serve to form the spinal canal, and to unite the vertebræ to each other. In Man, and other warm-blooded animals, the two surfaces of the body are nearly flat and are parallel to each other; and they are united to the corresponding surfaces of the neighbouring vertebræ by a disc of fibro-cartilage (§. 45), which extends through the whole space that intervenes between them, and which, being firmly adherent to both, prevents them from being far separated from each other.

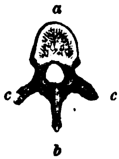

FIG. 215.—SINGLE VERTEBRA.

629. But in Reptiles and Fishes, a different plan is adopted. In the animals of the former class, particularly in Serpents, we find one surface of each vertebra *convex* or projecting, and the other *concave* or hollowed out; and the convex surface of each vertebra fits into the concave surface of the next, in such a manner that the whole spinal column becomes a series of ball-and-socket joints, and is thus endowed with that flexibility which is essential to the peculiar movements of these animals. In Fishes, *both* surfaces are concave; and between each vertebra there is interposed a bag containing fluid, and having two convex surfaces, over which those of the vertebræ can freely play. Extreme facility of movement is thus given to the spinal column; but its strength is proportionally diminished. It is to be remembered, however, that strength is not required in the bony framework

of animals whose bodies, instead of being supported upon four fixed points, are buoyed up in every part by a liquid of nearly the same density with themselves. The extreme flexibility of the spine of Fishes, enables them to propel their bodies by the movements of the hinder portion and tail, from side to side; their members, or pectoral and ventral fins (§. 99), being but little used, except for influencing the direction of their motion. And thus we see that, in the lowest Vertebrata, as in the lower Articulata (such as the Leech and Earth-worm), the propulsion of the body being accomplished by the movements of the trunk itself, its skeleton (internal in the one case, external in the other) is left in the soft condition, which it has in all at an early period; whilst in the higher classes of both series,—Birds and Insects, for example,—it undergoes great consolidation, its various pieces being so knit together, as to make the trunk almost immovable; the extremities being so developed, and being furnished with muscles so powerful, that the function of locomotion is entirely committed to them.

630. This knitting together is partly accomplished by means of projections or processes from the several vertebræ, which are united to one another by muscles and ligaments. Of these processes there are seven in Man from each vertebra. One of these, termed the spinous process (*b*, Fig. 215), projects directly backwards; and thus is formed the prominent ridge on the back, in which the ends of these projections can be distinguished. The spinous processes serve in Man, to give attachment to the muscles, by which the trunk and head are kept erect; in Animals whose spine is horizontal, they are generally much longer, in order to give firm attachment to the muscles and ligaments which support the head (Fig. 18). And in Fishes they are greatly prolonged, in order to increase the surface, by the stroke of which from side to side, the body is propelled through the water. On each side of the vertebra is a process (*c*, Fig. 215), which is called *transverse;* this serves for the attachment of the ribs to the vertebra. And lastly, from the upper and under side of each vertebra, two *articulating* processes project, which lock against each other in such a manner, as to prevent the movements

of the vertebræ from being carried to an injurious extent. These processes are peculiarly long in Birds, where they almost completely check the movements of the dorsal vertebræ; thereby giving to the trunk that firmness, which is required for the attachment of the muscles of the wings. The portions of bone which pass backwards from the body to the transverse processes, and form the side wall of the spinal canal, are called the *arches* of the vertebræ. These are the parts first formed. On the under edge of each, there is a notch, which corresponds with one in the upper side of the next; in such a manner that, when two vertebræ are placed together, a complete foramen or aperture is formed, which serves for the passage of the nerves that are given off from the Spinal Cord (§. 457).

631. The vertebral column of Man is disposed in a double curve, as seen in Fig. 214; the effect of this is to diminish the shock that would be produced by a sudden *jar*,—such as when a man jumps from a height upon his feet. If the vertebral column had been quite straight, this *jar* would have been propagated directly upwards from the pelvis to the head, and would have produced very injurious effects upon the brain; but by means of the double curvature, and the elasticity of the ligaments, &c. which hold together the vertebræ, it is chiefly expended in increasing, for a moment the curves of the spine, which thus acts the part of a spring. The constant pressure of the head and upper part of the trunk, has a tendency to increase these curves permanently, and thus to diminish the height of the body. The elasticity of the intervertebral substance, however, causes it to recover, during the time when the body is in the horizontal posture, the form it had lost by pressure in the upright position; and thus a man is taller, by half an inch or more, when he rises in the morning, than he was when he lay down the night before.

632. The first vertebra of the neck, termed the *atlas*, is much more movable than the rest, and differs considerably from them in its form. It is destitute of *body;* but it has a broad smooth surface on either side, on which rest the condyles of the occipital bone of the skull (§. 618), in such a manner that the head is

free to *nod* backwards and forwards. The atlas itself turns upon a sort of pivot, formed by an upward projection from the next Vertebra, which is termed the *axis;* this projection, called from its form the *processus dentatus* (or tooth-like process), occupies the place of the body of the atlas; and by the rotation of the atlas around it, the movements of the head from side to side are accomplished. Wherever great freedom of motion is permitted, displacement or dislocation is necessarily more easy; and accordingly we find that the atlas and axis can be more easily separated from each other, than can any other two vertebræ. This dislocation may be produced by violence of different kinds; thus if the head be suddenly forced forwards, while the neck is held back, the tooth of the axis may be caused to press against the spinal cord, and thus to interrupt or completely check its functions. Or, again, if the weight of the body be suspended from the head, and especially if it be thrown upon it with a jerk, the two vertebræ are liable to be dragged asunder, and the spinal cord to be stretched or broken. This is sometimes the immediate cause of death in hanging; and it has not unfrequently occurred when children have been held in the air, by the hands applied to the head,—a thing often done in play, but of of which the extreme danger should prevent its ever being practised. Any serious injury of the spinal cord in this region must be immediately fatal, for the reason formerly stated (§. 470),—that it causes the suspension of the motions of respiration.

633. The number of the ribs, which are attached to the bodies and transverse processes of the dorsal vertebræ, is, in the human species, 12 on each side.* The number in different animals may be judged of by that of the dorsal vertebræ in the table already given (§. 627); since it is the attachment of the ribs, that makes the essential difference between the *dorsal* vertebræ and the cervical or lumbar. The other extremity of each rib is connected with a cartilage, which is a sort of continuation of it; in Birds, the cartilages of the ribs are ossified or converted

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* It is scarcely necessary here to state, that the common notion respecting the deficiency of a rib on one side of the body of Man, is a popular error.

into bone. The cartilages of the first seven ribs (in Man), which are termed the *true* ribs, are united to the *sternum* or breast-bone, which forms the front wall of the thorax. The cartilages of the five lower ribs are not directly connected with this, and they are hence called *false* ribs; those of three of them, however, are connected with the cartilage of the seventh rib; and the other two ribs, being completely unattached at their anterior ends, are termed *floating* ribs. The *sternum* or breast-bone is flat and of simple form in Man; but it is much larger in many other animals. In those which have need of great strength in the upper limbs, such as Birds, Bats, and Moles, it is not only increased in breadth, but is furnished with a projecting keel or ridge, for the attachment of powerful muscles (§. 89). In the Turtle tribe, on the contrary, it is very much extended on the sides, so as to afford, with the ribs, a complete protection to the contained parts (§. 92).

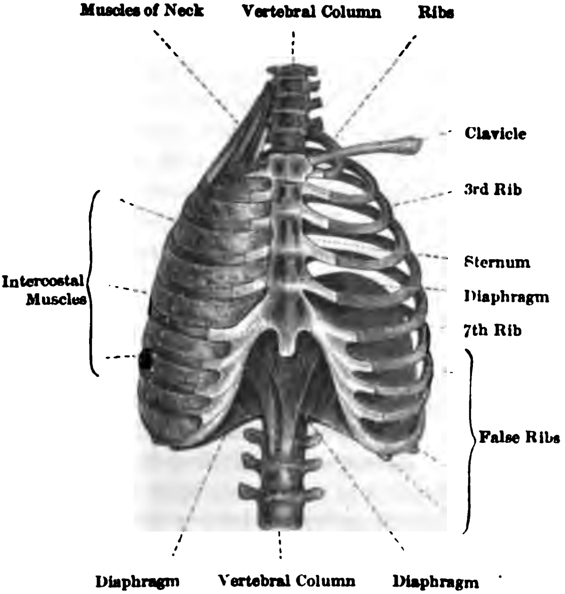

FIG. 216.—THORAX OF MAN.

634. We have next to consider the structure of the *members* or appendages, which are attached to this central frame-work. These are spoken of as *superior* and *inferior*, when treating of Man, whose erect posture places one pair above the other. But when the ordinary *Quadrupeds* are alluded to, they are termed *anterior* and *posterior*, one pair being in front of the other. Each member consists of a set of movable bones, which serve as levers; but the socket in which the first of these works, is formed by a bony framework, which is connected more or less closely with the spinal column. This framework, in the upper extremity, consists of the *Scapula* or blade-bone, and the *Clavicle* or collar-bone. In the lower extremity, it is formed by a set of bones, the union of which with the sacrum completes the *Pelvis* or bason, which is found at the bottom of the spinal column (Fig. 213).

635. The *Scapula* is a large flat bone, which occupies the upper and external* part of the back. Its form is somewhat triangular; and at its upper and external angle, is a broad but shallow cavity, destined to receive the head of the humerus or arm-bone. Above this cavity is a large projection, termed the *acromion process*, which is united by ligaments, &c., with the external end of the clavicle, and thus forms the bony eminence that we feel at the top of the shoulder. A little internally to this, we find another process, the *coracoid*, which only serves in Man for the attachment of certain muscles, but which in Birds is developed into a distinct bone (§. 89). The back surface of the scapula is divided into two, by a projecting ridge or keel, which gives a more extensive and firmer attachment to the muscles that arise from it. The scapula is never deficient in animals that possess a superior extremity, though sometimes it is very narrow. The muscles attached to it are chiefly those which draw the arm upwards, and which turn it on its axis. In Man, their actions are very numerous and varied; but in animals that only use their extremities for giving motion to the body, the muscular apparatus is much simpler, and the scapula

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* The term *external* is continually used in Anatomy, to describe the parts furthest removed from the *central* or *median line* of the body.

is narrower. This is particularly the case in Birds, the *raising* of whose wings in flight is an action that requires very little power, though for their *depression* or pulling-down, great muscular force is needed.

636. The *Clavicle* is a rounded bone, attached at one extremity to the acromion process of the scapula, and at the other to the top of the sternum. Its principal use is to keep the shoulders separate; and we accordingly find it strongest in those animals, the actions of whose superior extremities tend to draw them together; whilst it is comparatively weak, or altogether deficient, in the animals the actions of whose limbs naturally tend to keep them asunder. Thus we have seen that, in Birds, the violent drawing down of whose wings in flight would tend to bring the shoulders together, if they were not prevented, there is not only a strong clavicle, but usually a second bone, having a similar function (§. 89). Whilst, in the Horse and other animals the bearing of whose weight on their fore legs would tend rather to separate the shoulders than to bring them together, the clavicle is deficient.

637. The Scapula is connected with the central framework of the skeleton, by various muscles which pass towards it from the spinal column and ribs; and which serve alike to fix it, and to assist in sustaining the weight which it sometimes has to bear. In Man these are numerous, and their actions are various; since the scapula is left very movable in him, that the actions of the arm may be more free. In Quadrupeds it is generally more fixed; and the trunk is slung from it, as it were, by a muscle (the *serratus magnus*) of moderate thickness in Man, but in these animals of great strength, which passes from the scapula to be attached to the ribs.

638. The *superior* or *anterior member* itself is divided into three principal portions,—the arm, fore-arm, and hand. The arm is supported by a single long and cylindrical bone, which is called the *humerus;* this has a large rounded head, which is received into the glenoid cavity of the scapula; and at the bottom, it assists in forming the hinge-joint of the elbow. The muscles which move it are for the most part attached to its

upper third; and the chief of them are the *pectoralis major*, which rises from the sternum and cartilages of the ribs, and consequently draws the arm forwards, inwards, and downwards (when it is raised),—the *latissimus dorsi*, which rises from the spinal column and hinder part of the ribs, and consequently draws the arm backwards, inwards, and downwards,—and the *deltoid*, which arises from the upper edge of the clavicle, and from the ridge of the scapula, and is the chief muscle concerned in raising the arm. The first of these forms the principal part of the fleshy mass upon the front of the chest, and is the muscle which is so remarkably developed in Birds. It forms also the front boundary of the *axillary space*, or hollow of the arm-pit, the hinder boundary of which is formed by the second muscle. This space, of which we can distinctly feel the front and back walls when we raise the arm a little from the side, contains the large vessels and nerves proceeding to the arm, and also a number of lymphatic glands (§. 219). The deltoid muscle forms the thick fleshy mass on the top of the shoulder, and the upper part of the outside of the arm.

639. In the fore-arm of Man there are two long bones, termed the *Radius* and *Ulna;* which lie nearly parallel to each other. The radius is on the outer or thumb side of the fore-arm; and the ulna on the inner. They are connected with one another, not only by ligaments at their extremities, but by a strong fibrous membrane that passes between their adjacent edges, along their entire length. Nevertheless, they have considerable freedom of motion, not only upon the humerus, but upon each other. It is by this peculiar conformation, that the fore-arm possesses the power of rotation on its own axis, by which either the palm or the back of the hand may be turned upwards. The ulna is connected with the humerus, at the elbow, by means of a hinge-joint, into which the radius does not enter. But it is the radius with which the hand is connected at the wrist, by a kind of ball-and-socket joint, the ulna having no direct share in this articulation. Hence, while both bones move together in bending or straightening the elbow, we can make the radius roll round the ulna, carrying the hand with it.

This movement is one of very great importance, in rendering the hand capable of a great variety of uses, to which it would be otherwise inapplicable. It is only among the higher orders of Quadrupeds, however, that it can possibly be executed; for in the lower, the two bones are united more or less completely into one, or are articulated in such a manner as to be incapable of rotation.

640. The fore-arm is bent upon the arm, chiefly by muscles that lie upon the front of the latter; of these the principal is the *biceps* or two-headed muscle, which arises from the coracoid process of the scapula, and from the top of the glenoid cavity, and is inserted into the radius a little in front of the elbow, forming a great part of the fleshy mass in front of the arm (Fig. 209). The arm is straightened again by a large muscle, the *triceps*, or three-headed muscle, which arises from the back of the humerus and scapula, and passes down to be inserted into a projection of the ulna, behind the elbow joint, forming the fleshy mass at the back of the arm. The muscles which rotate the fore-arm arise from the lower end of the humerus, or from one of its bones, and pass obliquely to the other.

641. The *Hand* is anatomically divided into three portions,—the *carpus*, *metacarpus*, and *fingers*. The carpus, which is the portion nearest the wrist-joint, is composed of eight small short bones, which are firmly united to each other by ligaments, but yet have a certain degree of motion permitted them; these are arranged in two rows, of which one has a rounded surface, and enters into the formation of the wrist-joint; whilst the other has a series of shallowed pits, to receive the rounded heads of the metacarpal bones. These last almost precisely resemble the bones of the fingers (Fig. 213), and in the skeleton might be mistaken for their first joints; but, with the exception of that of the thumb, they are all united to each other by ligaments and muscles, so as to form the compact framework, which gives support to the palm of the hand. The metacarpal bone of the thumb is much more free in its movements; and it is chiefly by an alteration in its direction, that the thumb can be *opposed* to the fingers. These are formed by a series of small bones, which

are termed the *phalanges*; in these there are only two in the thumb, whilst there are three in the fingers. They are bent on each other chiefly by the action of the muscles that occupy the front of the fore-arm; and they are extended or straightened by others that lie along its back. These terminate in long tendons, which are bound down at the wrist by a fibrous band, that stretches between the bony processes on either side, and is termed the *annular* (or ring-like) ligament. The tendons then spread asunder in the hand, and pass on to be inserted into the bones of the several fingers, being reinforced by a set of small muscles that arise from the hand itself.

642. When we consider the superior extremity of Man as a whole, we remark that the several levers, which are joined end-to-end to form it, diminish progressively in length. Thus the arm is longer than the fore-arm; the latter is longer than the wrist; and each of the phalanges is longer than the one which succeeds it. The purpose of this arrangement is very evident. The numerous joints, in the neighbourhood of each other, which we see towards the extremity of the limb, permit its several portions to change their place in various ways, so as to accommodate themselves to the form of the body which it is desired to grasp; whilst the long levers formed by the arm and fore-arm, allow the place of the entire hand to be rapidly changed to a considerable extent. It is principally by the movements of the humerus upon the scapula, that the direction of the limb is given; the bending or straightening of the limb regulates its length; whilst the movements of the thumb and fingers are concerned in its particular application.

643. The hand of Man is distinguished from the extremity of most Quadrupeds by its possession of an *opposable thumb*,—that is, of a finger which can be made to act in a direction opposite to that of the rest. But among the Apes and Monkeys, we find this peculiarity, not only in the superior extremity, but also in the inferior; whence these animals are said to be *Quadrumanous* or four-handed, whilst *Man* is *Bimanous*, possessing two hands only. It must not be supposed, however, that Apes and Monkeys are superior in this respect to Man; for they possess

this distinguishing character in a much less striking degree than he does. All the four extremities of Apes and Monkeys possess the power of grasping, but they are all used also for support; and we find that, in consequence of the shortness of the thumb and great-toe, the grasping power is very inferior to that which we possess. But of the four extremities of Man, one pair is adapted for support, and the other for *prehension* or grasping; and this by the length and mobility of the thumb, which is capable of being brought into exact opposition to the extremities of all the fingers, whether singly or in combination. But even in those Quadrumana which most nearly approach Man, the thumb is so short and weak, and the fingers so long and slender, that their tips can scarcely be brought near to each other, and then with only a slight degree of force; hence, although completely adapted for clinging round bodies of a certain size,—such as the small branches of trees, &c.—the extremities of the Quadrumana can neither seize very minute objects with that precision, nor support large ones with that firmness, which is essential to the dexterous performance of a variety of purposes, for which the hand of Man is admirably suited.

644. In many of the inferior Mammalia, whose extremity is adapted for *support* only, we find each row of phalanges consolidated into two bones, or even into one. This is the case, for example, in the Ruminant Quadrupeds, as the Camel (Fig. 18), and in the Horse (§. 652). Such an arrangement obviously increases the firmness of the limb; but it altogether deprives it of prehensile power. In other instances, we find the number of bones in the hand increased, but all of them enclosed in one envelope, so that the fingers are not separate. This is the case with many aquatic animals,—such as the Whale tribe among Mammalia, Turtles among Reptiles, and Fishes in general,—in which the hand is made to serve as a fin or paddle. In most of these, the bones of the arm are very short; and the movements of the extremity are chiefly confined to the wrist-joint.

645. The structure of the lower extremities has a very great analogy to that of the upper; and the principal differences to be remarked between them, are such as are necessary to give to the

them more stability at the expense of freedom of motion, and to make them organs of locomotion instead of organs of prehension. Here, then, we have a bony framework, for the purpose of connecting the limb itself with the spine; and as the weight of the body is constantly thrown upon the lower extremities, this framework is much more firmly attached to that of the trunk, than is the case with that which supports the arms. It consists on each side of a bone, which, in the adult state, is single; though at an early age it is composed of three distinct pieces. This bone is closely connected with the sacrum behind, and in front it meets with its fellow; in such a manner as to form a sort of basin, termed the *pelvis*. The spreading sides of this, formed by the iliac bones (Fig. 213), afford support above to the viscera contained in the abdomen; and they give attachment by their surfaces to large muscles, by which the thigh-bone is moved; and by their edges to large expanded muscles, that pass upwards to the ribs and sternum, and form the walls of the abdomen. Below this spreading portion, we find the articular cavity, which is so deep as to be almost a hemisphere, when completed by its cartilaginous border. The movements of the thigh-bone are consequently more limited than those of the arm; but it is much less liable to displacement.

[illegible]. The thigh, like the arm, is supported by a single bone, which is named the femur. Its upper extremity is bent at an angle, and its rounded head is separated from the rest by a narrow portion, which is termed its neck. At the point where this neck joins the shaft of the bone, there are two large projections,—one on the outside, the other on the interior side,—which can be felt beneath the skin; and these serve to give attachment to the muscles by which the thigh is moved. Of these muscles, one descends from the lumbar vertebræ; and this, with another that rises from the upper expanded surface of the pelvis, passes down over the front border of the pelvis, and is attached to the smaller and interior of the projections just mentioned. These, with the assistance of other muscles, raise or draw forwards the thigh,—an action which does not require, in Man, to be performed with any great force. The muscles which draw back the thigh, on the other hand, arise from the under surface and back of the pelvis, where they form a very thick fleshy mass; and they pass to the larger and external projection, and to a ridge which runs down the thigh-bone. Other muscles, which arise from the lower border of the pelvis, serve to rotate the thigh upon its axis. The lower end of the thigh-bone spreads into two large *condyles*, on which the large bone of the leg moves backwards and forwards. The knee is a good example of a pure hinge-joint; all its movements being restricted to one plane.

647. The leg, although containing two bones like the fore-arm, does not possess the peculiar movement which characterises it. One of these bones, called the *tibia*, is much larger than the other, which is called the *fibula;* and it is the former alone which rests upon the thigh-bone, and which also gives the chief support to the foot, so that no movement of rotation is permitted in the leg. In fact, the fibula, which is a long slender bone, running nearly parallel with the tibia (Fig. 213), looks like a mere appendage or rudiment, and serves only for the attachment of muscles. The upper end of the tibia is broad, and has two shallow excavations, in which the condyles of the femur are received. Upon the front of the knee-joint, we find a small separate bone, the *patella* or knee-pan; the purpose of this is, to change the direction of the tendons that come down from the front of the thigh, to be attached to the tibia; in such a manner as to enable them to act more advantageously, upon the principle formerly stated (§.611). In the elbow-joint, this change was not required; since the ulna projects sufficiently far backwards, to afford advantageous attachment to the tendon of the extensor muscle. The very powerful muscles which tend to straighten the knee-joint, arise from the front of the pelvis, and from the femur itself; and they form the fleshy mass of the front of the thigh. On the other hand, those which bend the knee arise from the lower border of the pelvis, and from the back of the thigh-bone, and pass downwards to be inserted into the sides of the tibia and fibula a little below the knee, their tendons forming the two strong cords known as the *hamstrings*. The articulating surface at the lower extremity of the leg, which enters into the

ankle-joint, is principally formed by the tibia; but its outer border is formed by the fibula, which there makes a considerable projection, that can be felt through the skin.

648. The *foot* is composed, like the hand, of three distinct portions, which are called the *tarsus*, *metatarsus*, and *toes*. There are seven bones in the tarsus, all of which are larger than those of the carpus, and some of them of considerable size. The articulation with the leg is formed by one of these only, the *astragalus*, which projects above the rest, and is imbedded between the projecting extremity of the tibia (which forms the inner boundary of the ankle-joint) and that of the fibula. The astragalus rests on the *os calcis*, or bone of the heel, which projects considerably backwards, and is connected in front with the other bones of the tarsus. In front of the tarsus, we find the metatarsus, composed of five long bones, which in man are all attached to each other, but of which one is separate in the Quadrumana, in order to give freer play to the great toe, the action of which resembles that of the thumb. The toes, like the fingers, are composed of three phalanges (with the exception of the great toe, which has only two); these are in Man much shorter than those of the hand, and are evidently not adapted for prehension; but in many of the Quadrumana, their length is nearly equal to that of the fingers, and the great toe is as opposable as the thumb. The foot is far from being thus converted, however, into a perfect hand; but it becomes a very useful instrument for clasping the small branches and twigs of the trees, among which these animals live. The foot of Man is distinguished from theirs, by its power of being planted *flat* upon the ground, and thus of affording a firm basis of support. Even the Chimpanzee and the Orang, when they attempt to walk erect, rest upon the *side* of the foot; and the absence of a projecting *heel* causes them to be very deficient in the power of keeping the leg upright upon it. For it is to this projection, that the strong muscles of the calf of the leg are fixed, by which the heel is drawn upwards, or the leg drawn back upon it. Other muscles at the side and back of the leg, the direction of whose tendons is changed by a sort of pulley at the ankle-joint, aided by the muscles of the

foot itself, serve to bend the toes,—an action which gives great assistance in walking, running, leaping, &c. And they are straightened by an extensor muscle, which lies on the front of the leg, and of which the tendon runs under an *annular ligament* (§. 641) that encircles the ankle, and is then divided and spread out to the toes, over the upper surface of the foot. The great toe is a very important instrument in the act of walking, since much of the spring forwards is given by the bending of its phalanges; and it is provided with two flexor muscles of its own.

649. On the internal side of the foot, the bones of the tarsus and metatarsus form a kind of vault or arch, which serves to lodge and protect the vessels and nerves, that descend from the leg towards the toes. When this arrangement is not perfect (as sometimes happens), so that the foot is too flat, the nerves are compressed by the weight of the body, and the act of walking cannot be continued for a long time without pain. This arch further serves the important purpose of deadening the shock, that would otherwise be experienced every time that the foot is put to the ground; for by the elasticity of the ligaments which hold together the bones that compose it, a sort of *spring* is formed, which yields for a moment to the shock, and then recovers itself. We feel the difference which this makes, when we jump from a height upon our heels; the *jar* is then propagated directly upwards from the heel to the leg, thence to the thigh, and thence to the spinal column; and if it were not from the peculiar manner in which this is constructed (§. 631), a severe shock of this kind might produce fatal effects by *concussion* (or shaking) of the brain. In animals, which walk upon four extremities, the difference of direction in which the legs are connected with the spine, prevents a jar from being propagated along the latter, to a similar degree. But in those which are destined to obtain their food by sudden and extensive leaps, such as the animals of the Cat tribe (the Lion, Tiger, &c.), we find an arrangement of the bones of the foot, well adapted to diminish the shock produced by the sudden descent of the body upon the ground.

Of the Attitudes of the Body, and the various kinds of Locomotion.

650. A small number of Vertebrated animals,—Serpents, for instance,—bear habitually on the whole length of their bodies, which rest entirely on the ground; and their only movements are effected by undulations of the spinal column. But the rest are supported upon their extremities; and we give the name of *standing* to that position, in which the animal rests supported by its limbs, upon the ground or any firm horizontal basis. In maintaining this position, the *extensor* muscles, by which the joints are straightened, must be in continual action, since the limbs would otherwise bend beneath the weight of the body. Now as the sense of fatigue, in a set of muscles, depends in great degree upon the length of time during which they have been in action, the maintenance of the standing posture for a long period is, in most animals, more fatiguing than walking; since in the latter exercise, the action of the flexors alternates with that of the extensors.

651. But this condition is not the only one essential to steadiness in the standing posture; for in order that the body may rest firmly upon the members, it must be in *equilibrium*. It has been shown (Mechan. Philos. Chap. iv.) that equilibrium exists,—or in other words, that a body remains at rest in its position,—not only when it bears upon the whole of a broad surface, but also when it is so placed, that the tendencies of its different parts to descend or gravitate towards the earth, counterbalance each other. This is the case when its *centre of gravity* is supported,—that is, when a line drawn perpendicularly from it falls within the base. In order, then, that an animal may rest in equilibrium on its legs, it is necessary that the vertical line from its centre of gravity (or *line of direction*) should fall within the space which its feet cover and enclose between

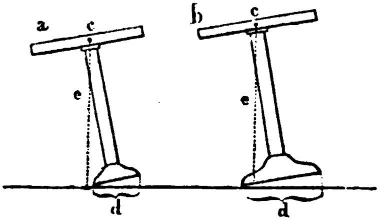

Fig. 217.

them; and the wider this space, in proportion to the height of the centre of gravity, the more stable will the equilibrium be, since the body may be more displaced without being upset. Thus in Fig. 217, the table *a* must be upset; because the line of direction, *e*, from the centre of gravity, *c*, falls outside the base of support, *d*: whilst the table *b*, although equally inclined, will not be upset, but will return to its proper place; because the line of direction, *e*, from *its* centre of gravity, *c*, falls within its base, *d*. Hence an animal which is supported upon four legs, will stand much more firmly than one which rests on two only; since its real base is the whole space included between its four points of support. And again, an animal is more firm when standing upon two legs, than when resting upon one only.

652. Moreover, when an animal rests upon four legs, the extent of its base is but little influenced by the size of the feet; and thus to render them broad, would be to increase their weight, without adding much to their use as supports. This is easily understood by comparing a quadruped to a four-legged table; if the legs are sufficiently strong to support the weight that rests upon them, it matters little in regard to the steadiness of the table, whether they bear upon the ground by mere points, or by flat surfaces; since it is the large surface that would be enclosed by lines joining them, which constitutes the real base. Hence we find that, in most quadrupeds, the limbs only touch the ground by slightly-dilated extremities; and the number of fingers is reduced more and more, without diminishing their effect as instruments of locomotion. Thus in the Ruminant animals, as the Deer, the number of toes is reduced to two in each foot, as seen in Fig. 218; where *t* represents the tibia, *ta* the bones of the tarsus, *c* the bone of the metatarsus termed the *canon* (in which the trace of a division into two

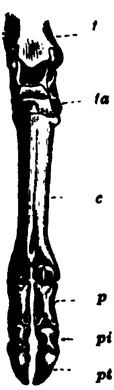

FIG. 218.

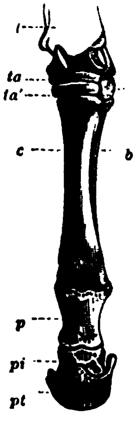

FIG. 219.

pieces can be seen), and *p*, *pi*, *pt*, the three phalanges of the toes, of which the last is enveloped in the hoof, which is nothing else than a large *nail* enclosing the whole extremity of the toe. In the Horse this consolidation is carried still further than in the Ruminantia; for it has only one toe in each foot; but we see the rudiment of an additional bone in the metatarsus (*b*, Fig. 219), which is commonly termed the *splint* bone.

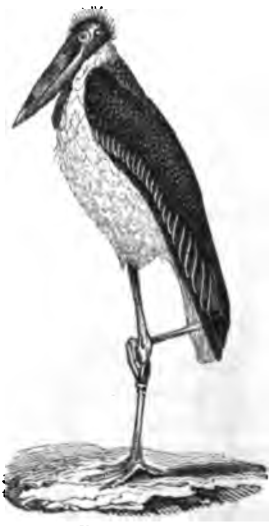

FIG. 220.—STORK.

653. But when an animal is supported upon two feet only, whatever may be their degree of separation from each other, the base of support cannot have sufficient extent, unless the extremities touch the ground by a considerable surface. This is the case with the foot of Man, and still more with that of many Birds which habitually stand upon one leg. In order that an animal may hold itself in equilibrium upon a single limb, it is necessary that the foot should be placed vertically beneath the centre of gravity of the body; and that its muscles should be so arranged, as to permit it to keep this limb inflexible and immovable. Man can accomplish this; for the centre of gravity of his body is about the middle of the pelvis; and to place this vertically over the foot, it is sufficient for him to bend himself a little from the side which is not supported. But the greater number of Quadrupeds are destitute of the power of doing this; and a large part of them cannot even raise themselves on their hind legs, on account of the direction of these members relatively to the trunk; or if they can do so for an instant, they cannot maintain themselves in this position. The reason of this is very simple. The base of support, on account of the smallness of the feet, is very narrow, and the centre of gravity of the body is placed nearer the front, towards

the chest; hence the body must be entirely changed in its position, by a violent and not sustainable action of the muscles which connect it with the hind legs; and, when thus reared up, it cannot rest with firmness, on account of the narrowness of the base.

654. There are some Quadrupeds, however, which are able to raise themselves occasionally into this position; this is the case, not only with the Quadrumana, but also with the Bear, Squirrel, and other animals whose habits require them to ascend and live among trees,—as well as in the Kangaroo, and animals constructed upon the same plan, whose peculiar organisation will be presently considered (§. 661). In maintaining the upright position, the muscles of the back part of the neck are kept in a contracted state, to retain the head in equilibrium on the vertebral column; and the extensor muscles of that column must also be kept in action, to prevent it from bending forwards under the weight of the head, upper extremities, and viscera of the trunk. The whole weight of the upper part of the body is thus transmitted to the sacrum, and thence to the other bones of the pelvis, by which it is brought to bear on the femur. If left to themselves, the thigh-bones would bend beneath the pelvis, and the trunk would fall forwards; but the contraction of their extensor muscles keeps them firm. In the same manner, the extensor muscles of the knee and ankle keep these joints from yielding beneath the weight of the body; and it is thus at last transmitted to the soil. The *sitting* posture is less fatiguing than the standing position, because the weight of the body is then directly transmitted from the pelvis to the base of support, so that it is not requisite for the extensor muscles of the lower limbs to keep up a sustained action. But the *lying* posture is that of the most complete rest; because the weight of every part of the body is at once transmitted to the surface on which it bears; and no muscular movement is requisite to keep it in its position.

655. This difference in muscular effort, is the cause of a well-marked variation in the pulse, according to the position in which the body is at the time. From a considerable number of obser-

vations it has been found that the average pulse of an adult man is about 81 when standing, 71 when sitting, and 66 when lying; so that the difference between standing and sitting was 10 beats or 1-8th of the whole, whilst the difference between sitting and lying was 5 beats or 1-13th of the whole. In the female, the pulse is quicker in each position by from 10 to 14 beats per minute; but the differences occasioned by position are nearly the same. It will be observed that the difference between standing and sitting is greater than that between sitting and lying; and this closely corresponds with the relative amounts of muscular exertion, required in these positions respectively. At the moment when the posture is changed, the pulse is considerably quickened; in consequence of the muscular effort required for the purpose, which acts especially on the veins, and forces the blood more rapidly back to the heart (§. 279): but this increase in rapidity is temporary only.

656. All that has been said of the positions of Vertebrated animals applies equally well to those of the Invertebrata which, like them, have the body raised from the ground upon extremities. This is the case in the higher Articulata, such as Insects, Crustacea, Arachnida, and Myriapoda. But the lower Articulata crawl, like Serpents, upon the whole length of their bodies; or, being aquatic, are buoyed up by the element they inhabit. And among the Mollusca and Radiata, there are none which have members, upon which they can be said to *stand*.

657. The progressive movements by which the bodies of Man and other animals are made to change their places, are accomplished by means of the alternate contractions and extensions of those limbs, which we have hitherto considered only as supporting them in a rigid position. It is easy to see that, when a joint is straightened after being bent, the two ends of the levers which form it, must be separated from each other; and that motion must thus be given to the parts, against which one or both of them bear. Now in the ordinary movements of progression, one of these levers bears against the ground, which is immovable; and the whole motion produced by straightening the joint, must consequently be communicated to the body. In the ordinary

act of *walking*, one of the feet is planted in front, whilst the other is extended or carried backwards beneath the leg, by the action of the muscles of the calf, aided by those of the toes (§. 648). Its length is thus increased; and as it bears upon the resisting soil, this elongation acts through the thigh upon the pelvis, and thus carries forward the whole body. At the same time, the pelvis makes a slight turn upon the femur of the other side, on which it is resting; and the limb, which was at first behind the other, is now drawn forward by a flexion of its joints, and is planted on the ground in front of the other, so as to serve for the support of the body in its turn; whilst the other, by extending itself, gives a fresh forward impulse to the body. Thus each limb is alternately made to support the whole weight of the body, just as it would do in standing on one leg; and at the same time, the other is engaged in urging it forwards. Hence the centre of gravity must vibrate a little from side to side, in the act of walking, so that it may be brought alternately over each foot; and this movement from side to side is the more obvious, in proportion as the pelvis is wider, and the limbs more separated from each other. Hence it is more seen in women than in men, on account of the greater proportional breadth of the hips in the former.

658. In all the higher animals, as in Man, there are members which serve for locomotion; but the nature of these movements varies greatly; and there is a corresponding difference in the structure of the instruments by which they are performed. The manner in which the Creator has made the same organs answer a variety of different purposes, in accordance with the habits of the animals to which they belong, is a most interesting object of study; for we see the most varied results attained, without the least departure from the general plan, which has been adopted in the construction of the various species of the same group; and this solely by slight changes in the forms and proportions of some of the instruments, the union of which makes up the entire body. The organs of locomotion in the Mammalia furnish us with obvious examples of this principle. This class includes not only the Quadrupeds which run or bound along the surface of the

ground,—but animals which are destined, like Fishes, to live solely in water,—others which, like Amphibia, sometimes swim through that element and sometimes inhabit the land,—others again which possess wings, that enable them to fly through the air like Birds,—and others which only employ their anterior members for grasping or feeling; yet in all these animals, these organs are constructed of the same parts. In the paddles of a Seal (Fig. 226), the wing of a Bat (Fig. 236), and the fore-paw of a Squirrel or a Mole, we find the same bones as in the arm of Man (Fig. 213). And even in the fore-legs of the Ruminant Quadrupeds, and in those of the *Solidungula*, or single-toed animals (such as the Horse), we can usually perceive traces of the existence of three or four toes, whose bones are more or less completely united.

659. From what has already been stated, as to the influence of the length of the levers on the quickness of the movement of the extremities (§. 614), it is easy to see that animals which have the most rapid progression, must necessarily have long members; since, the quickness with which the extensor muscles act remaining the same, the change of place in the free extremity of the lever will be greater, in proportion as that extremity is more distant from the point of insertion of the muscles that move it, and from the fulcrum on which the lever works. But in proportion to the elongation of this arm of the lever, must be the increase in the power of the muscles that move it, in order to overcome the same resistance; according to the general principle, that what is gained in velocity is lost in power. Hence, in order to endow an animal with great agility, it is only necessary to lengthen its limbs, and to render the muscles capable of exerting a proportional power.

660. We have seen that in *walking*, the body is sustained upon one limb (in *quadrupeds*, upon one pair of limbs), whilst it is pushed onwards by the other; so that it never ceases to bear upon the ground. In *running*, however, the body of Man momentarily quits its support at intervals; the foot in advance not being planted on the ground, at the time that the hinder one quits it. In this action, the Ostrich and its allies probably sur-

pass all other animals; as they can outstrip the fleetest horse at full gallop, or the swiftest grayhound at its greatest speed. The *amble* of Quadrupeds is a pace which resembles the walk or run of Bipeds, the two legs on one side being moved together, whilst the body rests upon the other. This pace is peculiar to the Giraffe, and to horses which have been trained to execute it. The *trot*, however, is a step of a different and much more secure nature. The fore-foot of one side is raised and advanced with the hind-foot on the other side; and when these are set down, the other fore and hind feet are raised and advanced together. Now, if we consider the fore-feet of a horse as constituting the four angles of a parallelogram, it is easy to see that the base of support, when the feet are thus raised, will be one of the diagonals; and as the feet are alternately advanced, the weight will alternately be thrown upon these two lines. But the centre of gravity in the horse, especially when carrying a rider, is in a point almost exactly above that at which these two lines cross; so that it is always supported either by one or the other. The *gallop* of greatest speed is a *run* performed on the same plan as the trot;—that is, the right fore and left hind feet leave and reach the ground together, and then the left fore and right hind feet are advanced. The *canter* is a kind of step altogether different. The four legs strike the ground successively, the left hind foot reaching it first, the right hind foot second, the left fore foot third, and the right fore foot fourth. The celebrated race-horse Eclipse, when galloping at liberty and with his greatest speed, passed over the space of 25 feet at each stride or leap; this he repeated $2\frac{1}{3}$ times in a second, so as to pass over 58 feet in that time, which was at the rate of nearly 4 miles in six minutes and two seconds. But this performance was completely surpassed by that of Flying Childers, who was computed to have passed over $82\frac{1}{2}$ feet in a second, or nearly a mile in a minute.

661. In *leaping*, the body is projected into the air by the sudden extension of the joints, especially those of the hinder part of the body, which had been previously bent; and having traversed a greater or less distance, the body comes again to the ground

and may be again projected. This is a kind of motion usually practised by many animals, whose structure is expressly adapted to it. Thus among Quadrupeds, we find several in which the hind legs are enormously elongated, for the purpose of giving greater quickness to the motion of the body; and their muscles are developed to an extraordinary degree, in order to supply the necessary force. This is the case among most of the animals of the order Rodentia, such as the Hare, Rabbit, Squirrel, &c.; but particularly in the Jerboa or Jumping Rat, and in the Kangaroo and its allies. In these animals the fore feet, which are little used for progression, are comparatively small; and in the last, they are less than half the length of the hinder limbs. The

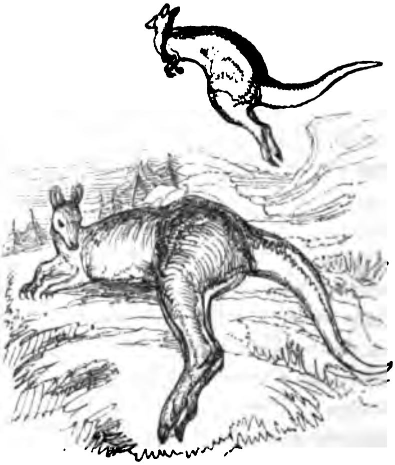

FIG. 221.—KANGAROOS.

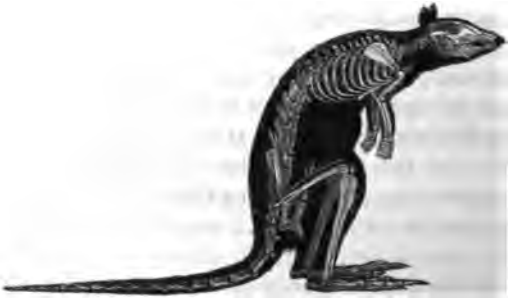

FIG. 222.—SKELETON OF KANGAROO.

feet as well as the legs of the Kangaroo are very long, in order to afford (in conjunction with the tail) a firm support to the animal when preparing to leap. Quadrupeds in which the length of the posterior extremities greatly predominates over that of the anterior, are observed to descend hills with difficulty at a rapid pace, since the forward inclination of their bodies places them in continual danger of oversetting; they therefore take a zig-zag course. In ascending a hill, however, their progression is greatly favoured by the length of their posterior extremities. The Rabbit, when moving slowly, advances the fore-feet two or three steps alternately, the posterior limbs remaining inactive; and the body having been lengthened by these means, the posterior legs are suddenly extended and drawn forwards simultaneously: thus the rabbit walks with the fore and leaps with the hind pair of legs. The Frog moves in a very similar manner.

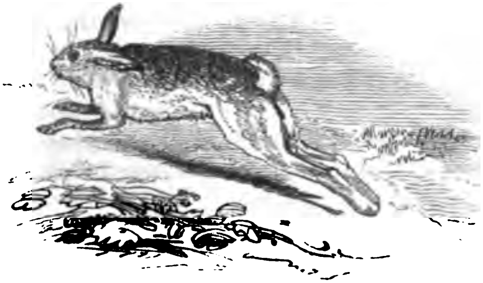

FIG. 223.—HARE ASCENDING A HILL.

662. It is among Insects that we find the most extraordinary powers of leaping, considered in regard to the size of the animals that possess them. Thus the Flea will spring to a height equal to 200

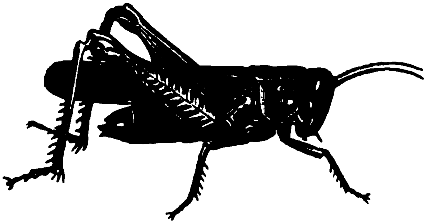

FIG. 224.—CRICKET.

times the length of its body. Let us imagine a Kangaroo or a Tiger doing the same! In many of the leaping insects, the hind legs are of great length, as in the Grasshopper and Cricket tribe; and in one curious family, that of the *Poduras* or Spring-tails, the leap is acomplished by the sudden extension of the tail, which is ordinarily bent under the body. A very remarkable kind of leap is executed by the Beetles of the family of *Elateridæ;* the larva of one species of which devours the roots of wheat, and is known under the name of the Wire-worm; whilst other species, which inhabit tropical climates, having the power of emitting light, are termed Fire-flies (§. 397). The legs of these insects are very short; so that, when they are laid on their backs, they cannot by means of them recover their natural position. This they are enabled to do, however, by their power of jerking backwards the head and upper part of the thorax, which causes the body to be projected vertically into the air, whence it usually descends with the feet towards the ground. The leap of the Crickets, Locusts, Frog-hoppers, &c. is executed more in a horizontal direction; and it is assisted by the wings, which bear up the body whilst it is moving onwards through the air. In this manner a Locust can traverse 200 times its length; and a Frog-hopper 250 times: which is as if a Man were to take a quarter of a mile at one leap.

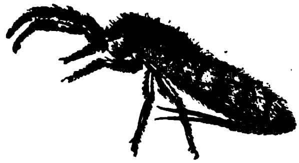

FIG. 225.—PODURA.

663. *Swimming* and *Flying* are movements which have much resemblance to each other; both being executed in a fluid medium, which, to a certain extent, buoys up the body,—which offers resistance to its progress,—and which also offers something resembling a fixed point, on which the members may act to propel it. The chief differences between them depend upon the nature of the medium,—this being liquid in the one case, and aeriform or gaseous in the other. The liquid medium affords more support to the body, and a firmer surface for the action of its propelling organs; but at the same time it offers more resistance to its progress. The movement of a body through the

atmosphere, as in flight, requires a considerable expenditure of power to keep it up; and the yielding nature of the element prevents the propelling organs from acting against a firm surface; but the onward movement, in consequence of the slight resistance, is easily accomplished.

664. When the feet of a Quadruped are to serve both as walking and swimming organs, the end is accomplished by the spreading of the fingers, and their union by means of a fold of skin, which is stretched over them; as the web of a swimming Bird is stretched over its toes, so as to make an oar or paddle of sufficiently wide surface. This is the case, for example, in the *Ornithorhyncus* of Australia (Fig. 101); or in the Otter of our own country. When the members are intended exclusively for swimming, however, they undergo more considerable modifications in structure. The parts corresponding with the arm and fore-arm are very short, and the movements of the hand are thus limited, but they can be accomplished with all the more force. But the bones of the hand are large and spread asunder, and are enclosed in a firm integument, which may even cover their extremities. Sometimes the number and arrangement of these bones are precisely the same as in the hand of Man; this we see in the Seal, where their extremities are furnished with separate claws, that project beyond the integument. Sometimes the number of phalanges in the fingers is considerably increased, as in the Whale; and in other instances, the fingers are replaced by a multitude of small rods of bone, enclosed within a continuous skin, such as we see in the fins of Fishes. (See Fig. 38.) In

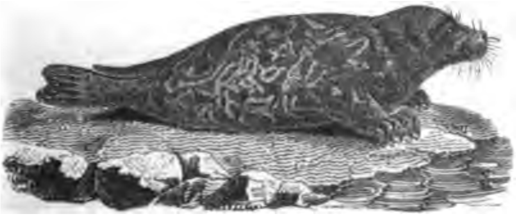

FIG. 226.—SEAL.

the Seal, which does not depart widely in its general construction from land Quadrupeds, the hind feet are formed upon the same plan as the fore; but they are carried far backwards, so as almost to occupy the position of the tail.

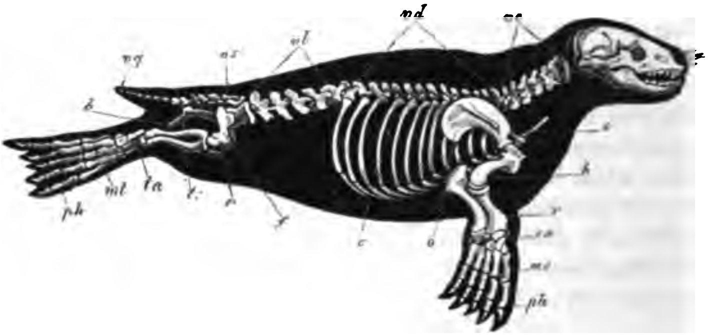

FIG. 227.—SKELETON OF SEAL.

vc, cervical vertebræ; *vd*, dorsal vertebræ; *vl*, lumbar vertebræ; *vs*, sacral vertebræ; *vq*, caudal vertebræ; *b*, pelvis; *s*, sternum; *h*, humerus; *r*, radius; *ca*, carpus; *mc*, metacarpus; *ph*, phalanges; *o*, scapula; *c*, ribs; *f*, femur; *r*, patella; *t*, tibia; *ta*, tarsus; *mt*, metatarsus; *ph*, phalanges.

665. In the Whale and its allies, on the other hand, the posterior extremities are almost entirely wanting, and the tail is greatly prolonged, and expanded at its extremity. This expansion, however, (which is in the *horizontal* direction) is not supported by bones, except in its centre; but it consists internally of cartilages and tendons, which last are prolonged from a set of

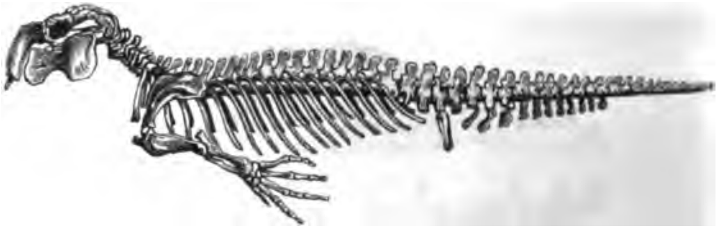

FIG. 228.—SKELETON OF DUGONG.

very powerful muscles that are attached to the spine, and give to this organ an enormous force and great variety of motion. The texture of the portion of it by which the blow is usually given, is such that it can hardly be injured; it is so tough that it cannot be torn, and so free from feeling, that a stroke of it against a hard substance gives no pain to the animal. If it strikes a boat across the middle with the edge, the boat is cut asunder as clean and suddenly as if by one stroke of a giant axe; whereas, if it strikes with the flat surface, the boat is driven to the depth of many fathoms with the swiftness of an arrow. Hence this tail is a most efficient instrument for the propulsion of the bulky body of the Whale through the water; and it is, in fact, its principal organ of locomotion. The paddles formed by the fore-feet are placed near the centre of gravity of the whole mass; and thus can readily exert their peculiar action, which is that of changing the direction of the movement, and especially of raising and lowering the body.

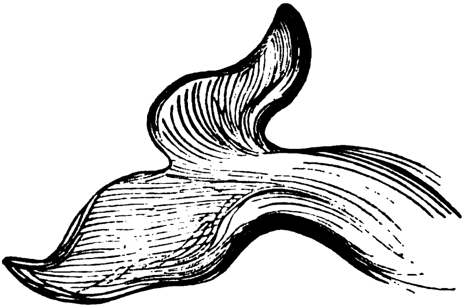
FIG. 229.—TAIL-FIN OF WHALE.

666. The propulsion of the body by the stroke of the tail in Whales and Fishes, is effected precisely in the same manner as the urging forwards a boat through the water, when accomplished by the motion of an oar at the stern from side to side,—in the mode commonly termed *sculling*. The expansion of the Whale's tail-fin being horizontal, its stroke is vertical, and may thus readily bring the animal to the surface of the water for occasional respiration, as well as propel it forwards; but that of the Fish's body and tail being vertical, its stroke is horizontal, and its action will simply be, to urge the body through the water. The power of ascending and descending, as well as of

changing the direction of the motion, is principally due to the side-fins, which represent the arms and legs. The direction of the surface and stroke of these side-fins varies in different species. In the Cod, Halibut, and others, their action appears to be principally directed towards keeping the body in its right position in the water; since, without such an action, the body would be liable to turn over, in consequence of the position of its centre of gravity. In other instances, the pectoral and ventral fins move in such a manner as to assist the action of the tail. In the Rays, the pectoral fins are developed to an enormous extent; and being directed horizontally, their action is vertical like that of the wings of a bird. They are furnished with a great number of joints, by which they are rendered very flexible; and their surface may be thus increased during the *down*-stroke of the fin, and diminished during the *up*-stroke. If this were not done, the action of the fins in elevation would exactly counterbalance the effect of their depression; and no movement would be produced. The great power of the pectoral fins of these Fishes seems connected with their want of an air-bladder, which causes them to require a constant exercise of force, to keep them up in the water. Their propulsion forwards is chiefly accomplished, as in other Fishes, by the action of the tail. But sometimes the Rays change their position, and swim sideways; making horizontal strokes with the pectoral fins (whose surface is then vertical), by which they are moved through the water; and sustaining themselves by vertical strokes of the tail, whose surface is then horizontal.

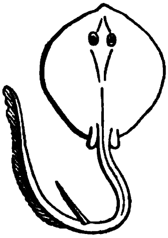

FIG. 230—RAY.

667. The structure of the organs adapted for movement in the air, bears great analogy to that of such expanded fins; and there are instances in which the same instruments may serve both purposes. Thus there are Fishes which are able to quit the water, and execute leaps of considerable length, supported upon their wing-like pectoral fins. These are known as Flying-Fish; but it is not correct to speak of their movement as one of

flight, since it does not appear that they have any power of propelling themselves in the air; the impulse being given at the moment of their quitting the water, in the manner of a leap. From 50 to 100 yards, however, are sometimes traversed by the Fish at one leap; and the height to which it rises from the surface of the water, is occasionally such as to carry it over the deck of a ship. On the other hand, there are several among the diving Birds, which use their wings as instruments of progression beneath the water,—in other words, as fins. The most remarkably-constructed of all these is the Penguin, in which the wings are so short as to be incapable of answering any other purpose; but there are several species, in which they may be used as organs of flight in the air, without losing their fin-like power in the water.

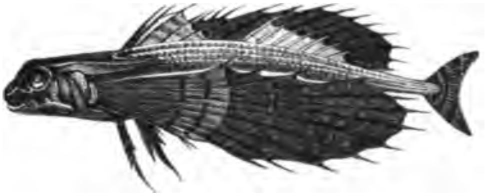
FIG. 231.—FLYING-FISH.

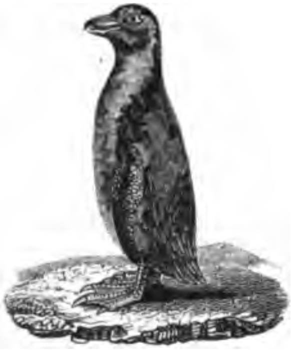
FIG. 232.—PENGUIN.

668. There are several animals that can sustain themselves for a short time in the air, by the aid of an expanded surface formed by an extension of the skin, and serving as a parachute. This is the case, for instance, with the Galeopithecus or Flying Lemur (Fig. 223), the Flying Squirrel, and the Flying Opossum, which have the skin stretched out on either side like a cloak, supported by the anterior and posterior extremities, and by the tail. By this parachute-like surface they are sustained in extensive leaps from bough to bough; though it does not enable them to support themselves in the air for any length of

time. In the *Draco Volans* (Fig. 234), a little animal which lives among the trees of tropical forests, the body is furnished with a wing-like appendage on either side; which is formed by an expansion of the skin over six lengthened ribs. These appendages serve as a kind of parachute, on which this little animal, not more than a few inches long, flutters from branch to branch in search of its insect prey, or shoots, like the flying squirrel, from tree to tree. They cannot be made to strike the air, and therefore are not true wings; but they can be folded up and extended at the will of the animal.

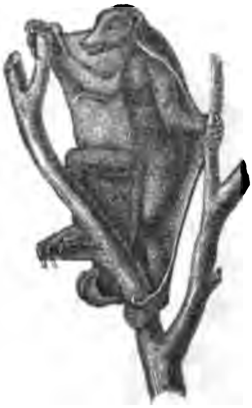

FIG. 233.—GALEOPITHECUS.

669. True *wings*, or instruments of propulsion as well as of support in the air, are found in some members of all classes of air-breathing Vertebrata; but they are especially characteristic of the class of Birds, in which class the *absence* of them is the exception to the general rule; whilst in Mammalia and Reptiles, it is their *presence* which constitutes the exception. These wings are universally formed by some modification of the anterior extremities, which renders them unfit to be used as instruments of progression on the ground; but the nature of this modifica-

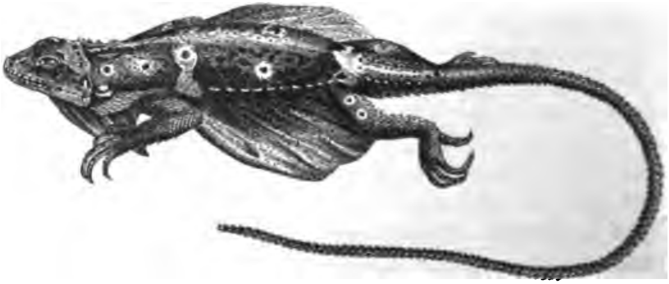

FIG. 234.—DRACO VOLANS.

tion varies considerably. We have seen that, in the Bird, the required extent of surface is chiefly given by the feathers (§. 87); these are supported upon an anterior member, of which the arm and fore-arm (especially the latter) constitute the largest part, the hand being contracted and consolidated (Fig. 235). But in the Bat, the plan is very different. We have here no long stiff feathers, by the projection of which from the limb itself, the surface may be increased to almost any extent; but the wing is formed by an expansion of soft and delicate skin, over a framework of bones, which must consequently be made to support it to its very edge. This is accomplished by the enormous extension of the bones of the hand, especially the metacarpal, which are here separate; and the membrane is farther sustained by the legs and tail. The thumb is not included in

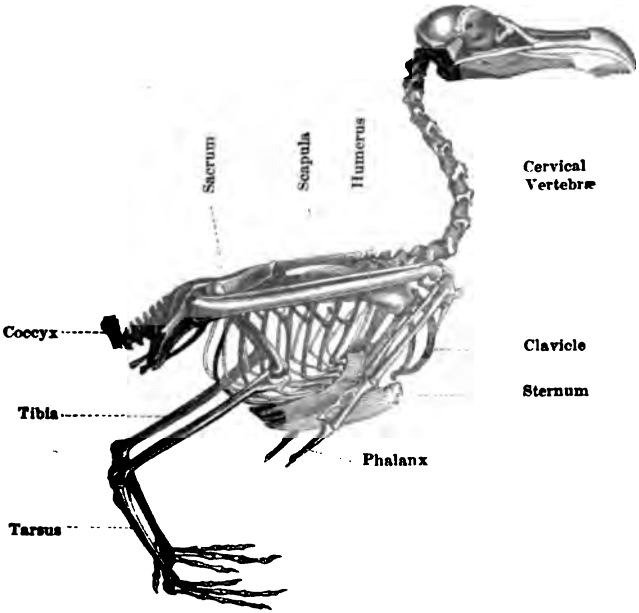

Fig. 235.—Skeleton of Bird.

the wing, but serves as a hook by which the animal can suspend itself. The only true flying Reptile is (or rather *was*) the

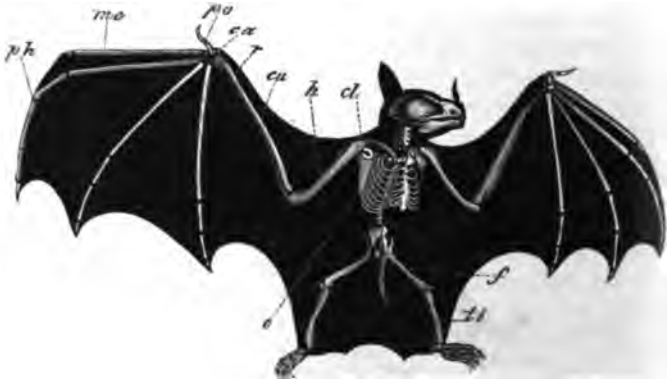

FIG. 236.—SKELETON OF BAT. (References as in FIG. 227.)

Pterodactylus, a kind of winged lizard, which does not now exist, but of whose character the skeletons that are found

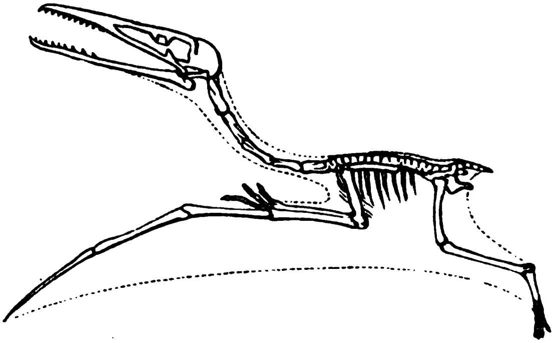

FIG. 237.—SKELETON OF PTERODACTYLUS.

imbedded in the earth afford most convincing proof. The structure of its wing differed from that of either Birds or Bats; for it appears, from the conformation of its anterior member, that the animal could have used it for resting or walking on, the framework of the wing being formed by the enormous elongation of one finger only.

670. The wings of Insects have no analogy whatever with those of Vertebrata, except in regard to their use, and in being composed of an expanded surface of membrane, stretched upon a hard framework. This framework is not composed, however, of solid pieces jointed together; but is merely an extension of the air-tubes and vessels within the body, which are strengthened by a continuation of its hard envelope. Their only action is a hinge-like movement at the point where they are united to the body; and this is accomplished by powerful muscles contained within the thorax.

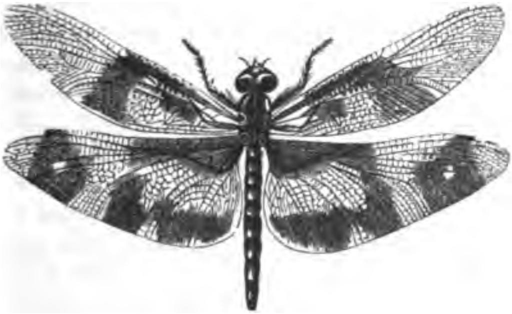

FIG. 238.—DRAGON FLY.

671. In all instances, the action of the wings must be such, that the air is struck with less force during the up-stroke, than during the down-stroke; otherwise the effect of the former would neutralise that of the latter. This is accomplished, partly by the great velocity of the down-stroke compared with the up-stroke, which causes the resistance of the air to be much greater in the former than in the latter.* But it is by the alteration in

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* This resistance varies as the *square of the velocity* of the stroke. Hence, if the down-stroke be made three times as fast as the up-stroke, the resistance it experiences will be nine times as great. But as this only operates during one-third of the time, it is in effect equal to three times that which operates against the up-stroke, and which would tend to lower the Bird in the air.

the surface of the wing, as it acts upon the air, that the chief difference is made. In Birds the arrangement of the great feathers is such, that they strike the air with their flat sides, but present only their edges in rising.* And in Insects, the expansion of the wings may be altered by the degree in which the air-tubes, that constitute the principal parts of their nerves or framework, are distended with air, by the pressure of the muscles contained in the body upon the air-sacs within.

672. The degree in which the wings act in raising the body, or in propelling it through the air, varies considerably in different animals, according to the way in which they are *set*. Thus in Birds of Prey, which require a rapid horizontal motion, the surface of the wings is very oblique, so that they strike backwards as well as downwards, and thus impel the body forwards whilst sustaining it in the air. Such Birds find a difficulty in rising perpendicularly; and can in fact only do so by flying against the wind, which then acts upon the inclined surface of the wings just as it does upon that of a kite. On the other hand, the Lark, Quail, and such other birds as rise to great heights in a direction nearly vertical, have the wings so disposed as to strike almost directly downwards. It has been estimated that a Swallow, when simply sustaining itself in the air, is obliged to use as much force to prevent its fall, as would raise its own weight to a height of about 26 feet in a second. Hence, we may form some idea of the enormous expenditure of force which must take place, when the body is not only supported, but raised and propelled through the air. The Eider-duck is said to fly 90 miles in an hour, and the Hawk 150. The Swallow and Swift pass nearly the whole of the long summer days upon the wing, in search of food for themselves and their helpless offspring; and the rapidity of their flight is such, that they can scarcely traverse less than seven or eight hundred miles in that time, although they go but a short distance from home. The flight of Insects is even more remarkable, for its velocity in proportion to their

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* What is called *feathering the oar* in rowing, is a similar operation, performed with the same intention, and deriving its name from this resemblance.

size; thus a Swallow, which is one of the swiftest-flying of Birds, has been seen to chase a Dragon-fly for some time without success; the Insect always keeping about six feet in advance of the Bird, and turning to one side and the other so instantaneously, that the Swallow, with all its powers of flight, and tact in chasing Insects, was unable to capture it.

673. If the preceding estimate of the power expended by a Bird in sustaining itself in the air be correct, it may be easily proved that it would be impossible for a Man to sustain himself in the air, by means of his muscular strength alone, in any manner that he is capable of applying it. It is calculated that a Man of ordinary strength can raise 13¼ lbs. to a height of 3¼ feet per second; and can continue this exertion for eight hours in the day. He will then exert a force capable of raising (13¼ × 60 × 60 × 8) 381,600 lbs. to a height of 3¼ feet; or one-eighth that amount, namely 47,700 lbs. to the height of 26 feet, which, as we have seen, is that to which the Bird would raise itself in one second, by the force it is obliged to exert, in order to sustain itself in the air. Now if we suppose it possible, that a Man could by any means concentrate the whole muscular power required for such a day's labour, into as short a period as the accomplishment of this object requires, we might find the time during which it would support him in the air, by simply dividing this amount by his weight, which we may take to be 150 lbs. The quotient is 318, which is the number of *seconds*, during which the expenditure of a force, that would raise 47,700 lbs. to a height of 26 feet, will keep his body supported in the air; and this is but little more than 5 minutes. There is no possible means, however, by which a Man could thus concentrate the force of eight hours' labour, into the short interval in which he would have to expend it, when supporting himself in the air. And we have elsewhere seen (MECHANICS, §. 285), that by no combination of mechanical powers can force be *created*; as these only enable force to be more advantageously applied. Hence, the problem of human flight will never be solved, until some source of power shall be discovered, far surpassing that which his mus-

cular strength affords, and so portable in its nature as not materially to add to his weight.

674. The only other organs of locomotion which we have to consider, are those of *prehension*. Of these, the principal have been elsewhere noticed, with reference to their use in laying hold of food, and conveying it to the mouth (§. 172), and with regard to the differences between the hand of Man and the claspers of the Quadrumana (§. 643). The hand of Man is seldom employed to assist in his locomotion, except in swimming (where it serves the purpose of a fin), and in climbing; neither of which kinds of movement can be said to be natural to him. But the claspers of the Quadrumana are most efficient instruments of locomotion; enabling them, not only to grasp the branches of the trees which they climb to despoil them of their fruit, but also to catch hold of them at the end of a long leap. This they do with the most wonderful agility; as all who have seen Monkeys in circumstances at all like those of their natural habitations, must have observed. The Gibbons or long-armed Apes of the East Indies, are probably the most remarkable in this respect. The Author has seen the *Ungkaputi* leap round and round a room of about 15 feet square, catching at each side by some small support attached to the wall; and taking its next leap (if such it could be called) by merely swinging itself from this, without touching anything solid with its feet. There are many of the Monkey tribe, however, especially in the New World, whose hands are less efficient as instruments of prehension; and these are furnished with a

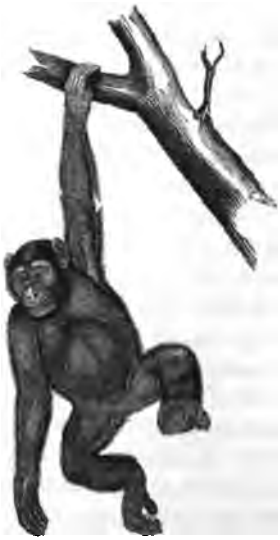

FIG. 239.—CHIMPANZEE.

prehensile tail,—that is, a tail which can be coiled round the branch of a tree, and by which the animal can suspend itself. A similar tail is possessed by some of the Opossum tribe; and by the Chameleon among Reptiles.

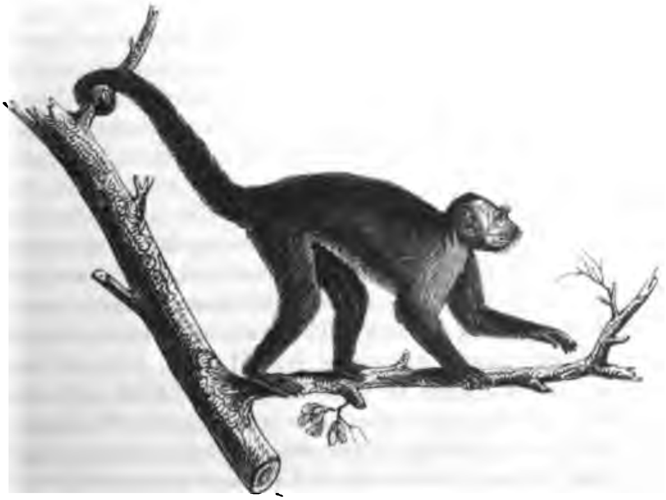

FIG. 240.—WHITE-THROATED SAJOU.

CHAPTER XIII.

OF THE VOICE.

675. It is not by their movements alone, that Animals are enabled to influence one another. Were it so, their communication would be restricted to the small amount which can be effected by signs and gestures. This, however, is necessarily the case amongst aquatic animals in general; since they are prevented, by the nature of their Respiration, from producing sounds through its means, which can be propagated to a distance. Some of them appear to have the power of communicating with each other, however, by the vibrations which they can excite in the water; of this we have already noticed an example among the Whale tribe (§. 491); and there is reason to believe, that some of the Mollusca have a similar means of communication.

676. Many Insects have the power of producing a continuous sound, which probably serves the purpose of intimating to each other the neighbourhood of their own kind; and even, in some instances, of expressing their feelings: some of these sounds are produced only during flight. Of this kind is the sharp hum of the Gnat, Mosquito, Gad-fly, &c., which is often a source of extreme annoyance to man and beast; but it serves to give warning of the proximity of these blood-thirsty Insects, and is therefore of real service to the animals they attack. From some recent experiments it appears, however, that in Bees and Flies at least, the sound is not produced so much by the vibrations of the wings (to which it is commonly attributed), as by the vibrations of a little membranous plate, situated in one of the spiracles or stigmata (§. 320) of the thorax; for if the apertures of these are stopped, no sound is heard, though the wings

remain in vibration. But in Cockchafers, and other noisy Beetles, Butterflies, &c., no such apparatus can be discovered. Other sounds are produced, while the Insect is feeding; that occasioned by the armies of Locusts, when incalculable millions of powerful jaws are in action at the same time, has been compared to the crackling of a flame of fire driven by the wind. Certain two-winged Flies, distinguished by a long proboscis (Fig. 241), make a humming sound, whilst sucking honey from flowers; and the same is the case with some of the Hawk-moths.

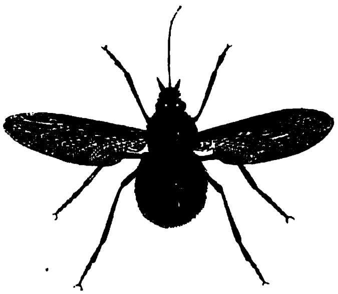

FIG. 241.—BOMBYLIUS.

677. Some Insects are remarkable for a peculiar mode of *calling*, *commanding*, or giving an *alarm*. The neuters or soldiers among the White Ants, make a vibrating sound, rather shriller and quicker than the ticking of a watch, by striking against hard substances with their mandibles; this seems intended to keep the labourers, who answer it by a hiss, upon the alert, and at their work. The well-known sound termed the Death-watch is produced by a small beetle (Anobium), that burrows in old timber; and it is occasioned by the striking of its mandibles upon the wood. The sound is evidently intended by the animal as a means of communication with its fellows; for if it be answered, it is continually repeated; whilst if no answer be returned, the animal repeats the signal in another place. The noise exactly resembles that produced by tapping moderately with the nail upon the table; and when familiarised, the insect will very readily answer this imitation. The most remarkable example of the production of sounds for the purpose of authority, is that of the Queen-Bee;

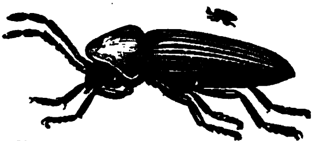

FIG. 242.—DEATH-WATCH, NATURAL SIZE AND MAGNIFIED.

which has the power of influencing the whole hive, especially about the time of swarming, by the peculiar notes she produces.

678. Many Insects have the power of expressing their passions, also,—as fear, anger, sorrow, joy, or love,—by the sounds they can generate. The most curious of those given out under the influence of *alarm*, is that produced by the *Sphinx Atropos*, or Death's-head Hawk-moth; which, when confined, or taken into the hand, sends forth a strong and sharp cry, resembling, some say, that of a mouse, but more plaintive, and even lamentable. The means by which this cry is produced, have not yet been certainly ascertained. The influence of *anger*, *sorrow*, and *joy*, in modifying the tone of the hum of Bees, is well known to those who have studied their habits; the first is particularly evident in the sharp angry tone which is heard, when the hive has been disturbed, especially if some of the Bees have been killed; the second is manifested in a low plaintive tone, which is given out when the queen has been taken away; and the cheerful humming which is immediately heard, when the sovereign is restored, is an evident indication of the last. "But *love* is the soul of song, with those that may be esteemed the most musical Insects,—the Grasshopper tribes, and the long celebrated Cicada."* Of the Grasshopper tribes belonging to this country, the most noisy are the *Crickets;* whose sound is produced by the rubbing of the *elytra*, or wing-covers, one against the other. In several species it may be distinctly seen, that a very strong nervure, on one of these, has a jagged surface like that of a file; and that this works against a collection of smaller nervures, which resemble so many strings. The merry

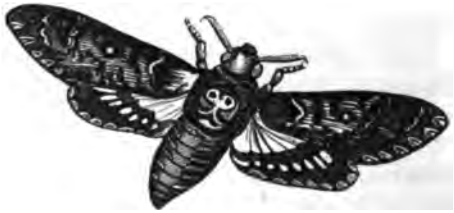

FIG. 243.—SPHINX ATROPOS.

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* Kirby and Spence's Entomology, Vol. II. Chap. XXIV., whence these details are derived.

inhabitant of our dwellings, the House-Cricket, though it is often heard by day, is most noisy in the night; as soon as it grows dusk, its shrill note increases till it becomes quite an annoyance, so as even to interrupt conversation, and prevent sleep; some persons, however, have a fondness for their sound, and have kept them for their amusement.

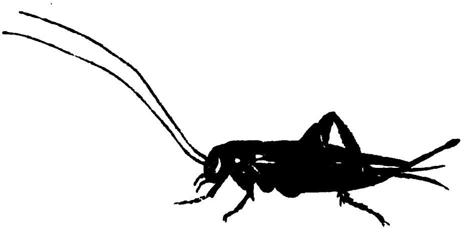

FIG. 244.—HOUSE-CRICKET.

679. The *Cicada* was a very favourite insect among the ancient Greeks; and was frequently mentioned by their poets, with the most endearing epithets. Its song was considered particularly musical; and it was regarded as the happiest, as well as the most innocent of animals,—perhaps for the amusing reason given by one of their bards;—

> "Happy the Cicada lives,
> Since they all have voiceless wives."

The Cicadæ of other countries produce an extremely shrill and disagreeable sound, which can be heard at a great distance. In the warmer parts of the United States, there is a species which, in the hotter months of summer, is a very troublesome and impertinent neighbour, "perching upon a twig, and squalling sometimes two or three hours without ceasing, especially from midday to the middle of the afternoon, thereby too often disturbing the studies or short repose that is frequently indulged, in those hot climates, at those hours." The Cicadæ of Brazil are said to be audible at the distance of a mile: this is as if a Man of ordinary stature, supposing his powers of voice increased in the ratio of his size, could be heard all over the world. The organs by which the sound is produced, are placed on the under side of the body, between the base of the hind legs and the abdomen; and consist externally of a pair of large flattened plates of a horny texture, varying in form in the different species. When these are raised, they are found to conceal a large cavity partially covered with a membrane of a much more delicate nature than the external covering, with a horny plate in the middle, which lies along the bottom. Still more internally, are two bundles of muscles, which are the real agents in producing the sound; for, when they are pulled, and suddenly let go, even in a dead specimen, the sound is produced as well as though the insect were alive. They act by drawing in and forcing out, by their alternate and rapid contraction, a horny *drum* or membrane, stretched in such a manner as to vibrate readily; the sound occasioned by the movements of which, passes out through an aperture resembling the sound-holes of a violin. The *Fulgoræ*, also, have considerable sound-producing powers; but sing in the night, whilst the Cicadæ perform in the day. The Great Lantern-fly of Guiana (§. 400, Fig. 163), begins regularly at sunset; and its noise, resembling that of a razor-grinder at work, is so loud, that the insect is called Scare-sleep by the Dutch colonists.

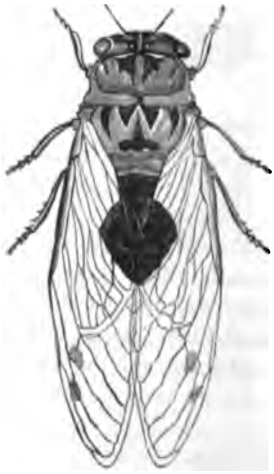

FIG. 245.—CICADA.

680. In all air-breathing Vertebrata, the production of sound depends upon the passage of air through a certain portion of the respiratory tubes, which is so constructed as to set the air in vibration. In Reptiles and Mammalia, it is at the point where the windpipe opens into the front of the pharynx, that this vibrating apparatus is situated. Few of the animals of the former class, however, can produce any other sound than a *hiss*, occasioned by the passage of air through the narrow chink, by which the trachea communicates with the pharynx; but this sound, owing to the great capacity of their lungs (§. 325), is often very much prolonged. In the Mammalia, on the other hand, there are few, if any, which have not some *vocal* sound;

but the variety and expressiveness which can be given to it, differ considerably in the several tribes of the class, being by far the greatest in Man. This sound is produced by the apparatus termed the *larynx*, which is situated beneath the base of the tongue, and in front of the pharynx (§. 192, Fig. 105). It is suspended, as it were, from the *hyoid bone* (*h*, Fig. 246),—a bone of a horse-shoe form, detached from the rest of the skeleton; from two projections (*l*), on the upper side of which, several of the muscles of the tongue originate. The sides of the larynx are formed by two large cartilages (*t*, Fig. 246), which are termed the *thyroid* cartilages; where these meet on the middle line, a projection is formed, which is particularly prominent in Man, and has received the name of *Pomum Adami*, or Adam's Apple (*a*). The thyroid cartilages rest upon another, termed the *cricoid* (*c*); this has the form of a ring, much deeper behind than in front, and surmounts the trachea, with the upper ring of which its lower edge is connected, by a membrane. Upon the upper surface of the back of the cricoid cartilage, where there is an open space left between the two thyroid cartilages, are mounted two small cartilaginous bodies, the *arytenoid* (*ar*, Fig. 247). These are movable to a certain extent; and their position

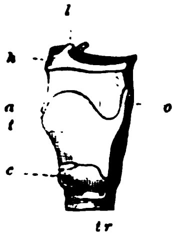

FIG. 246.—HUMAN LARYNX, VIEWED SIDEWAYS.

h, hyoid bone; *l*, point of origin of muscles of the tongue; *t*, thyroid cartilage; *a*, projection in front, commonly called Adam's apple; *c*, cricoid cartilage; *tr*, trachea; *o*, posterior side of the larynx, in contact with the œsophagus.

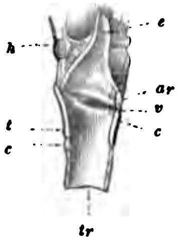

FIG. 247. — VERTICAL SECTION OF THE LARYNX.

ar, arytenoid cartilages; *v*, ventricle of the glottis; *e*, epiglottis;—the other references as before.

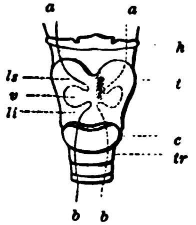

FIG. 248.—FRONT VIEW OF THE LARYNX.

The interior wall is marked by the lines *a*, *a*, *b*, *b*;—*li*, inferior ligaments of the glottis, or vocal cords; *ls*, superior ligaments;—the other references as before.

may be changed in various directions, by several muscles which act upon them.

681. To these arytenoid cartilages are attached two ligaments, of elastic fibrous substance (§. 29), which pass forwards, to be attached to the front of the thyroid cartilage, where they meet in the same point. These are the instruments concerned in the production of sound, and also in the regulation of the aperture by which air passes into the trachea; and they are usually termed the *vocal cords* or *ligaments*. By the meeting of these ligaments in front, and their separation behind, the aperture has the form of a V; but it may be narrowed by the drawing together of the arytenoid cartilages, until the two vocal ligaments touch each other along their whole length, and the aperture is completely closed. In this manner, the amount of air permitted to pass through the larynx is regulated; and a protection is afforded against the entrance of solid substances. An additional guard is afforded by the doubling of the lining membrane, in such a manner as to form a second pair of folds (*l*, *s*, Fig. 248), above the preceding; and over the space between these (which is much wider than that between the vocal cords) there is a valve-like flap, the *epiglottis* (*e*, Fig. 247), which is pushed down upon it in the act of swallowing, so as to prevent the entrance of solid or fluid particles into the space beneath, which is called the *glottis*. From the causes formerly mentioned (§. 193), such particles are occasionally drawn into the glottis; and they excite, by a *reflex* action, an involuntary and extremely violent cough, which tends to expel them again. Sometimes, however, solid bodies of no inconsiderable size find a lodgment in the wide spaces (*v*, Fig. 248) between the upper and lower pair of ligaments, which are termed the *ventricles* of the larynx; and occasionally they pass through the opening between the vocal cords, which is termed the *rima glottidis* or fissure of the glottis, into the wind-pipe.

682. In the ordinary acts of inspiration and expiration, the arytenoid cartilages are wide apart, so that the aperture is as large as possible; but for the production of vocal sounds, it is necessary that the aperture should be narrowed, and that the

flat sides, rather than the edges, of the vocal ligaments should be opposed to one another. This is accomplished by a peculiar movement of the arytenoid cartilages, occasioned by the contraction of certain muscles. When this is the case, the air, in passing through the larynx, sets these ligaments in vibration; in a manner very much resembling that in which the *reed* of a Hautboy or Clarionet, or the *tongue* of an Accordion or Æolina, is set in vibration by the current of air that is made to pass beneath them. The rapidity of the vibrations, and consequently the *pitch* of the sound (§. 523), depends on the degree of *tension* or tightness of the vocal ligaments; and this is regulated by muscles which act upon the thyroid and arytenoid cartilages. If the thyroid cartilage be drawn forwards, and the arytenoid cartilages backwards, the two ends of the vocal cords will be further separated from each other, and they will consequently be tightened; by the contrary movements they will be relaxed.

683. The power which the will possesses, of determining, with the most perfect precision, the exact degree of tension which these ligaments shall receive, is extremely remarkable. Their average length in the male, in a state of repose, is estimated at about 73-100ths of an inch; whilst in the state of greatest tension, it is about 93-100ths; the difference is therefore about 20-100ths, or 1-5th of an inch. In the female glottis, the average dimensions are about 51-100ths, and 63-100ths, respectively; so that the difference is only 12-100ths, or less than 1-8th, of an inch. Now the natural compass of the voice (or distance between its highest and lowest notes) in most persons who have cultivated the vocal organ, may be stated at about two octaves, or 24 semitones. Within each semitone, a singer of ordinary capability could produce at least 10 distinct intervals; so that, for the total number of intervals, 240 is a very moderate estimate. There must, therefore, be at least 240 different states of tension of the vocal cords, every one of which can be at once determined by the will; and the whole variation in their length being not more than 1-5th of an inch, even in Man, the variation required to pass from one interval to another will not be more than 1-1200th of an inch.—And yet this estimate

is much below that which might be truly made, from the performance of a practised vocalist. It is said that the celebrated Madame Mara was able to sound 100 different intervals between each tone. The compass of her voice was at least 20 tones; so that the total number of intervals was 2000, all comprised within an extreme variation of 1-8th of an inch: hence it may be said that she was able to determine the contractions of her vocal muscles to the 1-16,000th of an inch.

684. It is on account of the greater length of the vocal cords, that the *pitch* of the voice is much lower in Man than in Woman; but this difference does not arise until the end of the period of childhood,—the size of the larynx being about the same in the Boy and Girl, up to the age of 14 or 15 years, but then undergoing a rapid increase in the former, whilst it remains nearly stationary in the latter. Hence it is that Boys, as well as Girls and Women, sing *treble;* whilst Men sing *tenor*, which is about an octave lower than the treble, or *base*, which is lower still.—The cause of the variations of *timbre* or *quality* in different voices, is not certainly known; but it appears to be due, in part, to differences in the degree of flexibility and smoothness in the cartilages of the larynx. In women and children these cartilages are usually soft and flexible, and their voices clear and smooth; whilst in men, and in women whose voices have a masculine roughness, the cartilages are harder, and are sometimes almost completely ossified. The *loudness* of the voice depends in part upon the force with which the air is expelled from the lungs; but the variations in this respect which exist among different individuals, are due to the degree in which its resonance is increased, by the vibration of the other parts of the larynx, and of the neighbouring cavities. In the Howling Monkeys of America, there are several pouches which open from the larynx, and are destined to increase the volume of tone that issues from it; one of these is excavated in the substance of the hyoid bone itself, which is very greatly enlarged; and to this bony drum seems due the mournful plaintiveness, which characterises the tone of these animals. Although the largest of the American Monkeys, these Howlers are of inconsiderable size; yet their

voices are louder than the roaring of lions, being distinctly audible at the distance of two miles; and, when a number are congregrated together, the effect is terrific.

685. In Birds, the situation of the vocal organ is very different. The trachea opens into the Pharynx, as in Reptiles, by a mere slit; the borders of which have no other movement, than that of approaching one another, so as to close the aperture when necessary. But at the *lower* extremity of the trachea, just where it subdivides into the bronchial tubes, there is a sort of larynx or vocal organ, which is of very complex construction, especially in the singing-birds. The external surface of this larynx is represented in Fig. 249; its muscles, *m*, *m'*, being left in their places on one side, and removed on the other. At *t t*, is seen the trachea; at the lower extremity of which, *t'*, is a sort of bony drum, *l*, divided at its lower part by a partition of the same material (*o*, Fig. 250), which is surmounted by a semilunar membrane (*c*, Fig. 250). This drum communicates below with the two bronchial tubes, *b b'*, each of which has its own glottis and vocal cords; the inner lip of one of these is seen at *a* (Fig. 250); and at *me* is shown a drum-like membrane, forming the inner wall of the bronchial tube, which probably increases the resonance of the voice. These parts are acted on by several muscles, the number of which varies according to the compass and flexibility of the voice in the different species; being very considerable in the most esteemed of the singing-birds, and being reduced to a small amount in those which have no vocal powers. In some, indeed, they are altogether absent; and the state of the glottis can be influenced only by those muscles which raise and lower the whole trachea.

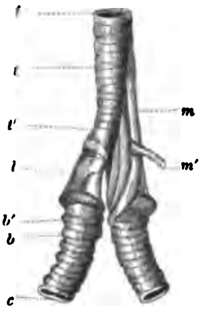

FIG. 249.—LARYNX OF A ROOK.

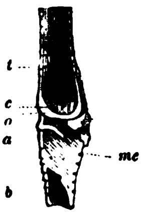

FIG. 250.—VERTICAL SECTION OF THE SAME.

686. The vocal sounds produced by the action of the larynx

are of very different characters; and may be distinguished into the *cry*, the *song*, and the ordinary or acquired *voice*.—The *cry* is generally a sharp sound, having little modulation, or accuracy of pitch, and being usually disagreeable in its timbre or quality. It is that by which animals express their unpleasing emotions, especially pain or terror; and the Human infant, like many of the lower animals, can utter no other sound.—In *song*, by the regulation of the vocal cords, definite and sustained musical tones are produced, which can be changed or modulated at the will of the individual. Different species of Birds have their respective songs; which are partly instinctive, depending upon the construction of their larynx; and are partly governed by their education. In Man, the power of song is entirely acquired; but, when once acquired, it is far more susceptible of variety and expression, than that of any other animal. In fact the larynx of Man may be said to be the most perfect musical instrument ever constructed.—The *voice* is a sound more resembling the cry, in this,—that it does not consist of sustained musical tones; but it differs from the cry, both in the quality of its tone, and in the modulation of which it is capable by the will. In ordinary conversation, the voice passes through a great variety of musical tones, in the course of a single sentence, or even a single word,—sliding imperceptibly from one to another; and it is when we attempt to fix it definitely to a certain pitch, that we change it from the *speaking* to the *singing* tone.

687. It is to the wonderful power that Man possesses, of producing *articulate* sounds, which form a medium by which he can communicate ideas of any kind to his fellows,—that much of his superiority to other animals is due. Nevertheless, it is not to this alone that we must attribute it; for many animals, especially Birds, can produce, by *imitation*, sounds as articulate as those of Man; but the *mind* which originates them, and which uses them as expressions of its ideas and desires, is deficient.

688. All spoken language is made up of a certain number of *elementary sounds*, which are combined into syllables, words, and sentences. It may be easily shown, upon arithmetical principles, that from 20 or more of these elementary sounds, an

almost infinite variety of combinations may be produced; and from such an inexhaustible store, there is no difficulty in deriving new combinations, to represent any new ideas that we may desire to express. These simple or elementary sounds ought to be represented by an equal number of single letters; this is the case, however, in but few languages. Our own is particularly faulty in this respect; for there are many simple sounds, that can be only represented by a combination of letters; whilst others may be represented by more than one single letter; and in some instances, a single letter represents a composite sound. Thus the sounds of *au* and *th* are really simple ones, and ought to be represented by single letters. Again, the sound of *k* is represented also by the hard *c*, as in the first syllable of *concert;* and the sound of *s* by the soft *c*, as in the second syllable of the same word, where the *c* is sounded exactly as the *s* in *consent.* And the letter *i* (as usually pronounced in English) does not represent a simple sound, but a combination of two, as will be presently shown. Most of the Continental languages are superior to the English in this respect.

689. Vocal sounds are divided into Vowels and Consonants; the true distinction between which appears to be, that the Vowel sounds are *continuous tones*, modified by the form of the aperture through which they pass out; whilst in giving utterance to Consonants, there is a partial or complete interruption to the breath, in its passage through the organs in front of the larynx. Hence all true Vowels may be prolonged for any length of time, that the breath is supplied from the lungs; whilst the sound of many Consonants is momentary only. It is easy for any one to convince himself that the Vowel sounds are governed simply by the form of the cavity of the mouth, and by that of the aperture of the lips, by passing, in one continued tone, from one of the following vowel sounds to another.

English *a* . .	as in *ah* . .	Continental *a*
English *a* . .	as in *all* . .	Diphthong *au*
English *a* . .	as in *name* . .	Continental *e*
English *e* . .	as in *theme* . .	Continental *i*
English *o* .	as in *cold* . .	Continental *o*
English *oo* . .	as in *cool* . .	Continental *u*

The *short* vowel sounds, as *a* in fat, *e* in met, *o* in pot, &c., are not capable of being prolonged; as they are formed in the act of preparation for sounding the succeeding consonant. The sound of the English *i* is a compound one, being formed in the act of transition from that of *a* as in *ah*, to that of *e* as in *theme*; hence it cannot be prolonged; and it is the very worst vowel sound upon which to sing a long note, since it is impossible to prevent its being heard as one of the sounds of which it is composed. Much discussion has taken place, with reference to the true characters of the letters *w* and *y*, when employed to commence words, as *wall*, *yawl*, *wet*, *yet*. A little attention to the state of the mouth in pronouncing them will show, however, that they are *then* really vowel sounds, rapidly transformed into the succeeding ones; for the sound of *w* in this situation is *oo*; and that of *y* is the long *e*; so that *wall* might be spelt ŏŏall, and *yaul* ēaul.

690. Consonants are naturally divided into those, which require a *total* stoppage of the breath, at the moment previous to their being pronounced, and which cannot therefore be prolonged; and those, in pronouncing which the interruption is partial, and which can be prolonged like the vowels. The former are termed *explosive* consonants; the latter *continuous*. The explosive consonants are *b* and *p*, *d* and *t*, the hard *g* and *k*. All the others are continuous; but the sound is modified by the position of the tongue, palate, lips, and teeth; and also by the degree in which the air is permitted to pass through the nose.

691. The study of the mode in which the different consonants are produced, is of particular importance to those who labour under defective speech, especially that difficulty which is known as *stammering*. This very annoying impediment is occasioned by a want of proper control over the muscles concerned in articulation; which are sometimes affected with a kind of spasmodic action. It is in the pronunciation of the consonants of the explosive class, that the stammerer usually experiences the greatest difficulty; for the total interruption to the breath, which they occasion, is frequently continued involuntarily, so that either the expiration is entirely checked, or the sound comes out in jerks.

Sometimes, on the other hand, in pronouncing vowels and continuous consonants, the stammerer prolongs his expiration, without being able to check it. The best method of curing this defect (where there is no malformation of the organs of speech, but merely a want of power to use them aright), is to study the particular defect under which the individual suffers; and then to make him practise systematically the various movements concerned in the production of the sounds in question, at first separately, and afterwards in combination, until he feels that his voluntary control over them is complete. *

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* For a fuller consideration of this subject, see the Author's Human Physiology, Chap. VI.

CHAPTER XIV.

OF INSTINCT AND INTELLIGENCE.

692. It will be remembered that, when the Nervous System was described (Chap. xi.), it was shown to be the instrument of three classes of operations, each of which seems to be performed by a distinct portion of the system. — I. The first of these is the class of *Reflex* actions, which are executed only in respondence or answer to the impression made, by certain agents operating upon the nerves proceeding to a ganglionic centre; as when a Dytiscus, whose head has been cut off, executes swimming movements, immediately that its feet come in contact with water. These actions are evidently performed without any choice or direction on the part of the animal, which, in executing them, seems like a mere machine, adapted to perform certain actions when certain springs are touched; and it has been shown that they may take place, even without its consciousness. Of these reflex movements, the Spinal Cord of Vertebrata, and in Invertebrata, the ganglia corresponding to it (in regard to their connections with the organs of locomotion, respiration, &c.) are the instruments.—II. The second class comprehends the Instinctive and Emotional actions, which differ from the preceding, in being dependent on the *Sensations* received by the animal, and in being, therefore, never performed without its consciousness. Nevertheless, the animal in executing them is not guided by any perception of the object to be attained, or by any choice of the means by which it is to be accomplished; but acts blindly and involuntarily, in accordance with an irresistible impulse, implanted in it by its Creator for the purpose of doing that, *without* or even *against* its Will, which it would not have chosen or

devised by its very imperfect intelligence. The Actions of this class are most wonderful in the Invertebrata, which possess the least Intelligence; and, on the contrary, they are fewest and least remarkable in Man, whose Intelligence is highest. From the constant proportion which they bear to the size of the ganglia of sensation, which form nearly the whole nervous mass in the head of Insects, &c., and a large part of that of the lower Vertebrata, but which are comparatively small in the Mammalia, and especially in Man, there seems good reason to regard these organs as their chief instruments.—III. The third and highest class of actions, is that in which Intelligence is the guide, and the Will the immediate agent. The animal receives sensations, forms a notion of their cause, reasons upon the ideas thus excited, perceives the end to be attained, chooses or devises the means of accomplishing it, and voluntarily puts those means into execution. These actions are seen, in their highest and most complete form, in Man; but they are not confined to him; for, as will be shown hereafter, true reasoning processes are performed by many of the lower animals. There can be no doubt that the Cerebral hemispheres, which form the *Brain* properly so called, constitute the instrument by which these actions are executed; for we find their size and development bearing a very regular proportion to the degree of Intelligence which the animal possesses.

693. It follows, then, that the lower we descend in the scale of Animal life, the larger is the proportion of the movements of any particular species, which we are to attribute to the Reflex and the Instinctive classes; whilst the proportion, which is due to Intelligence and Will, diminishes in a like degree. Thus we have seen that the ordinary movements of locomotion, which are for the most part voluntary in Man, are reflex in Insects (§. 445); and perhaps it would not be wrong to suppose, that the movements of the tentacula of the Hydra, by which it entraps its prey and draws it to the entrance of its stomach (§. 14), are of a reflex, rather than a voluntary or instinctive character, since they are obviously analogous to the movements of the pharyngeal muscles, by which the food is grasped, and carried into the alimentary

tube, in the highest animals (§. 195). There is one curious fact, which would seem to indicate a difference between them, but which is really a strong argument in favour of their analogy. It is continually observed that, when the stomach of the Polype is full, its arms do not make any attempt to seize objects that touch them; so that small worms, insects, &c., which would at other times be entrapped, may now come near them with impunity. It has been supposed that this results from an act of *choice* on the part of the animal, and that its choice is influenced by its consciousness that its stomach is supplied with food. It must seem improbable that an Animal, which so nearly resembles Plants in its general habits, and in which the nervous system is so obscure that it has not yet been discovered, should possess mental endowments of so high a character; and we may find, in studying our own functions, a circumstance exactly parallel to that just mentioned. For when we commence eating, with a good appetite, we may notice that the muscles of Deglutition act very readily; but when we are completely satisfied, it is often difficult to excite these muscles to contraction, so as to swallow another morsel, even though for the gratification of our palate we may desire to do so. Thus we see how much better a guide we find in Nature, for the amount of food we require, than in our own pampered tastes.

694. The *first* class, that of Reflex Movements, has been already considered in sufficient detail; but it is intended, in the present Chapter, to offer some examples of those of the *second* and *third* classes,—those actions, namely, which are guided by *Instinct* and *Intelligence* respectively. These actions may be usually distinguished by the two following tests:—1. Although in most cases, experience is required to give the Will command over the muscles concerned in its operations, no experience or education is required, in order that the different actions, which result from an Instinctive impulse, may follow one another with unerring precision. 2. Instinctive actions are performed by the different individuals of the same species, nearly, if not exactly, in the same manner; presenting no such variation of the means applied to the objects in view, and admitting of no such improve-

ments in the progress of life, or in the succession of ages, as we observe in the habits of individual Men, or in the manners and customs of nations, which are for the most part adapted to the attainment of particular ends, by voluntary efforts guided and directed by reason.—Where, as in the examples hereafter to be mentioned (§. 717), we find individual animals "learning wisdom by experience," and acquiring the power of performing actions which do not correspond with their natural instincts, we cannot do otherwise than regard them as possessed of a certain degree of intelligence, by which they are rendered susceptible of education.

695. The *amount* of intelligence displayed in these acquirements, can only be judged of, however, by carefully examining the circumstances under which they are made. If the new habits are gained by imitation simply,—as is the talking of a Parrot,—no great degree of intelligence is manifested; but if it spontaneously result from a reasoning process on the part of the animal, our idea of its sagacity is raised. There may be a combination of both these conditions; as in the following curious circumstance, related to the Author by a friend who has repeatedly witnessed it. Some horses kept in a paddock, were supplied with water by a trough, which was occasionally filled from a pump, — not, however, as often as the horses seem to have wished; for one of them learned, of his own accord, to supply himself and his companions, by taking the pump-handle between his teeth, and working it with his head. The others, however, appear to have been less clever or more lazy; and finding that this one had the power of supplying their wants, they would tease him, by biting, kicking, &c., until he had pumped for them, and would not allow him to drink until they were satisfied. That this was not a mere act of *imitation*, appears from the circumstance, that the horse did not attempt to imitate the movement of the man, but performed the same action in a different manner,—evidently because it had *associated* in its mind, the motion of the pump-handle with the supply of water.

696. The Instincts of Animals may be shown to have immediate reference, probably in every instance, to the supply of the

wants of the individual, or to the continuance of the race. Thus we have Instincts which guide in the selection and acquirement of food; others which govern the construction of habitations for the individual, and of receptacles for the eggs,—and these may influence a number at once, in such a manner as to unite them into a society; others which direct their emigrations, whether in search of food, for the deposit of their eggs, or for other purposes. Of these, some examples will now be given.

697. Among the instincts which direct animals in the acquirement of their food, few are more remarkable than those possessed by the larva of the *Ant-lion*, a small insect allied to the Dragon-fly. This animal is destined to feed upon ants and other small insects, whose juices it sucks; but it moves slowly and with difficulty; so that it could scarcely have obtained the requisite supply of food, if Nature had not guided it in the construction of a remarkable snare, which entraps the prey it could not acquire by pursuit. It digs in fine sand a little funnel-shaped pit (Fig. 253), and conceals itself at the bottom of this, until an insect falls over its edge; and if its victim seeks to escape, or stops in its fall to the bottom, it throws over it, by

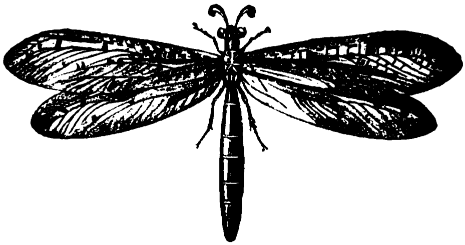

FIG. 251.—ANT-LION, IN PERFECT STATE.

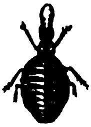

FIG. 252.—LARVA OF THE ANT-LION.

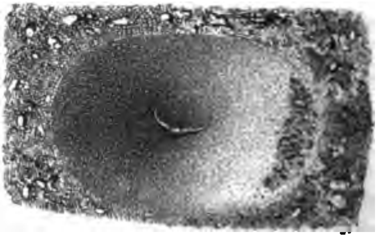

FIG. 253.—PITFALL OF THE ANT-LION.

means of its head and mandibles, a quantity of sand, by which the insect is caused to roll down the steep, within reach of its captor. The manner in which the Ant-lion digs this pit is extremely curious. After having examined the spot where it purposes to establish itself, it traces a circle of the dimensions of the mouth of its pit; then, placing itself within this line, and making use of one of its legs as a spade, it digs out a quantity of sand, which it heaps upon its head, and then, by a sudden jerk, throws this some inches beyond its circle. In this manner it digs a trench, which serves as the border of its intended excavation, moving backwards along the circle, until it comes to the same point again; it then changes sides, and moves in the contrary direction, and so continues until its work is completed. If, in the course of its labours, it meets with a little stone, the presence of which would injure the perfection of its snare, it neglects it at first, but returns to it after finishing the rest of its work, and uses all its efforts to get it upon its back, and carry it out of its excavation; but if it cannot succeed in this, it abandons its work and commences anew elsewhere. When the pit is completed, it is usually about 30 inches in diameter, by 20 in depth; and when the inclination of its walls has been altered by any slip, as almost always happens when an insect has fallen in, the Ant-lion hastens to repair the damage.

698. Snares of a still more singular character are constructed by many Spiders, which spin webs of the finest silk, for the purpose of entrapping their prey. The arrangement of these toils varies according to the species, and sometimes does not present any regularity; but in several instances it is of extreme elegance; and no one can watch the labours of a common garden spider (as, for instance, the *Epeira*

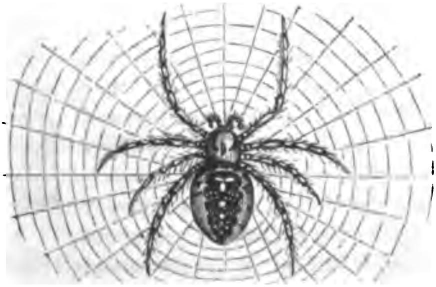

Fig. 254.—Epeira Diadema.

diadema, Fig. 254), without being struck with the marvellous sagacity which it displays in the execution of its work, and the perfection with which its web is constructed.

699. An equally curious instinct is often displayed in the construction of the habitations which the animal designs for its abode. Thus the Hamster, a small rodent animal allied to the Rat, which is met with in most cultivated districts on the Continent from Alsace to Siberia, and which is very injurious to agriculture, constructs a burrow in the soil, which has always two openings,—one in an oblique direction, which serves the animal for casting out the earth it has dug away,—the other perpendicular, which is the passage by which it enters and makes its exit. These galleries lead to a regular series of circular excavations, which communicate with each other by horizontal passages; one of these cavities, furnished with a bed of dried herbage, is the abode of the Hamster; and the others serve as magazines for the provisions, which it collects in large quantities.

FIG. 255.—HAMSTER.

700. There are certain Spiders known to Zoologists under the name of *Mygales*, which perform operations analogous to those of the Hamster, but still more complicated; for not only do they excavate in the ground a large and commodious habitation, but they line it with a silken tapestry, and furnish it with a door regularly hung upon a hinge. For this purpose, the Mygale digs, in a clayey soil, a sort of cylindrical pit, about 3 or 4 inches in length; and plasters its walls with a sort of very consistent mortar. It then

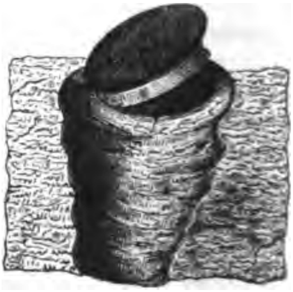
FIG. 256.—NEST OF MYGALE.

constructs, of alternate layers of earth, and of threads woven into a web, a trap-door exactly adapted to the orifice of its hole, and only capable of opening outwards; and it attaches this by a hinge of the same thread, to the tapestried lining of its chamber. The outside of this trap-door is covered with materials resembling the soil around; and so little does it differ from this, that it is with difficulty distinguished, even by a person seeking to discover the Spider's habitation. If an attempt is made to lift it, when the animal is within its excavation, the effort is resisted by the whole force of the Spider, which holds down the door, by fixing its claws into small holes on its under surface, at the point most distant from the hinge, where its force may be most advantageously applied.

701. Among Insects, we find a great number of very curious processes, instinctively performed in the construction of their habitations. Many Caterpillars form themselves a protection, by rolling together portions of leaves, and attaching them by threads. In almost every garden, we may observe (at the proper season) nests of this kind, on the leaves of the Lilac or Gooseberry; and a similar one, represented in Fig. 257, is constructed in the leaves of the Oak, by the caterpillar of a small nocturnal Butterfly; the *Tortrix viridissima.* The larva of the little Clothes-Moth, again, forms a sort of tubular sheath, composed of the filaments it detaches from the stuff, through which it excavates its galleries; this sheath it is continually prolonging at one extremity; and when, in consequence of the growth of the larva, its tube becomes too small for its comfortable residence, it slits it down, and lets in a piece. The aquatic larvæ of the Caddice-flies (Fig. 258, c), which are commonly known as *Caddice-worms*, house themselves in straws, pieces of hollow stick, rushes, &c.; and those of some species glue together a number of minute stones, pieces of stick, small shells, &c., so

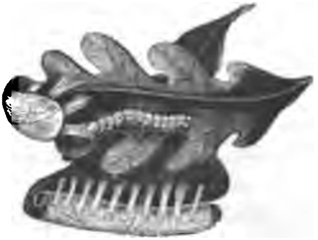

FIG. 257.—NEST OF TORTRIX.

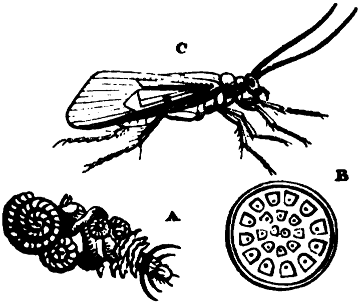

FIG. 258.—C, PHRYGANEA OR CADDICE-FLY. A, its tube; B, network at the entrance of the tube.

as to make a tube (A), in which the animal creeps along the bottom and sides of the brook it inhabits, and sometimes rows itself on the surface of the water. When full-grown, the larvæ attach their cases to some large stone by threads; and then close the mouth of the case with an open net-work of threads (B), sufficiently close to prevent the entrance of insects, but with meshes permitting the water to pass through. In this state they undergo their metamorphosis into the Pupa state; and a short time before their last metamorphosis, they cut the threads of the network by means of two hooks, with which their heads are furnished, and creep out of the water; soon after which they change into the perfect insect.

702. It is scarcely possible to point to any actions better fitted to give an idea of the nature of instinct, than those which are performed by various Insects, when they deposit their eggs. These animals will never behold their progeny; and cannot acquire any notion from experience, therefore, of that which their eggs will produce; nevertheless they have the remarkable habit of placing, in the neighbourhood of each of these bodies, a supply of aliment fitted for the nourishment of the larva that is to proceed from it; and this they do, even when they are themselves living on food of an entirely different nature, such as would not be adapted for the larva. They cannot be guided in such actions by anything like *reason;* for the data on which alone they could reason correctly, are wanting to them; so that they would be led to conclusions altogether erroneous if they were not prompted, by an unerring *instinct*, to adopt the means best adapted for the attainment of the required end.

703. Of this kind of instinct, the *Necrophorus*, a kind of Beetle not uncommon in our fields, offers a good example.

When the female is about to lay her eggs, she seeks for the dead body of a Mole, Shrew, or such other small quadruped; and having found one, she excavates beneath it a hole of sufficient dimensions to contain the body, which she gradually drags into it; she then deposits her eggs in the carcase, so that the larvæ, when they come forth, find themselves in the midst of a supply of carrion, on which they feed, like their parents. This instinct is still more remarkable, when an Insect, whose diet is exclusively vegetable, prepares for its larva a supply of animal food. Such is the case with the *Pompilus*, an Insect allied to the Wasp. In its perfect state, it lives entirely on the juices of flowers; but the larvæ are carnivorous; and the mother provides for them the requisite supply of the food they require, by placing in the nest, by the side of the eggs, the body of a Spider or Caterpillar, which she had previously killed by means of her sting. The *Xylocopa* or Carpenter-Bee, has very analogous habits; the female makes long burrows in wood, palings, &c., in which she excavates a series of cells; and in every one of these she deposits an egg, with a supply of pollen-paste.

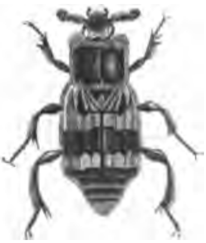
FIG. 259.—NECROPHORUS.

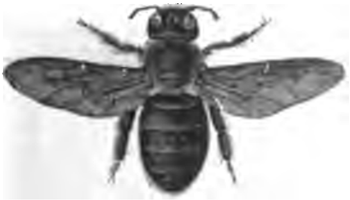
FIG. 260.—XYLOCOPA.

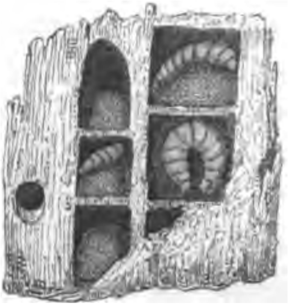
FIG. 261.—NEST OF XYLOCOPA.

704. The instinct of support and protection to the young

and helpless offspring, is seen in all animals in which it is needed; and it is particularly observable in Birds. The nests which they construct are destined much more for the reception of their eggs, and for the protection of the young, than for their own residence; for there are few Birds which pass much time in their nests, except at night, and during the period of incubation. It is impossible to watch the process of their construction, without admiring the perseverance with which these interesting animals bring together the materials that are destined for their erection, and the art with which they are arranged. The form and structure of these habitations are always nearly the same, among the individuals of the same species; but there is necessarily a certain latitude in regard to the materials of which they are composed, since the same could not be everywhere procured. The nests of different species vary greatly, however, both as to form, structure, and materials; and these are admirably adapted to the particular circumstances, in which the young families are respectively destined to live. Sometimes these habitations are constructed of earth, the particles of which are united by the

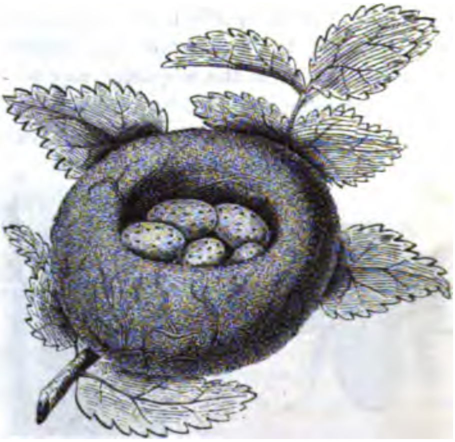

FIG. 262.—NEST OF GOLDFINCH.

viscid saliva of the Bird, into a tenacious mortar; and they are then commonly built against the sides of a rock or wall. But, in general, they are composed of sticks, straws, and other vegetable substances, and are placed either on the ground, or among the branches of trees. The greater number of them have a somewhat hemispherical form, resembling a little round basket; and their interior is lined with moss and down (Fig. 262).

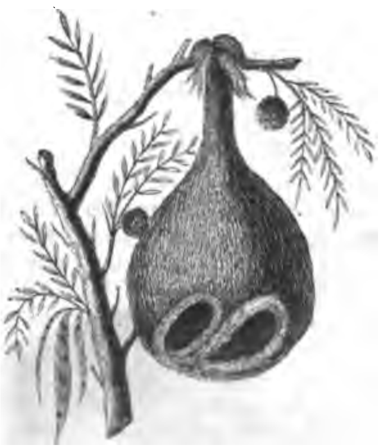

FIG. 263.—NEST OF THE BAYA.

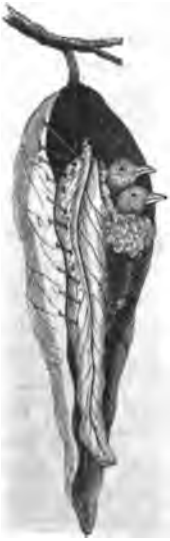

FIG. 264.—NEST OF THE TAILOR-BIRD.

705. But sometimes the arrangement is much more complicated, in order that some particular danger may be avoided, or some special purpose answered. Thus the nest of the Baya, a little Indian bird allied to our Bulfinch, has the form of a bottle; and it is suspended from a twig of such slenderness and flexibility, that neither Monkeys, Serpents, or Squirrels can reach it (Fig. 263). That it may be still more secure against the attacks of its numerous enemies, the Bird forms the entrance of the nest on its under side, so that it can itself only reach it by the aid of its wings. This curious habitation is constructed of long grass; and several chambers are found in its interior, of which one serves for the female to sit on her eggs, whilst another is occupied by the male, who solaces his companion with his song, whilst she is occupied in maternal

cares. Another curious nest is that of the *Sylvia sutoria*, or Tailor-bird, a little Eastern bird allied to our linnet; which, by the aid of filaments of cotton drawn from the Cotton-plant, sews leaves together with its beak and feet, in such a manner as to conceal the nest which they enclose from the observation of its enemies (Fig. 264).

706. The association of a number of individuals of certain species, for the performance of labours in which they all unite to one common end, is another most remarkable example of the operation of instinct. Several Mammalia exhibit this tendency in a greater or less degree; but the most interesting of all, in this point of view, is the Beaver, which is now chiefly found in Canada, though it formerly abounded on the Continent of Europe. During the summer, it lives solitarily in burrows, which it excavates for itself on the borders of lakes and streams; but as the cold season approaches, it quits its retreat, and unites itself with its fellows, to construct, in common with them, a winter residence. It is only in the most solitary places, that their architectural instinct fully develops itself. Having associated in troops of from two to three hundred each, they choose a lake or river, which is deep enough to prevent its being frozen to the bottom; and they generally prefer running streams, for the sake of the convenience which these afford, in the transporta-

FIG. 265.—BEAVER.

tion of the materials of their erection. In order that the water may be kept up to a uniform height, they begin by constructing a sloping dam; which they form of branches interlaced one with another, the intervals between them being filled up with stones and mud, with which materials they give a coat of rough-cast to the exterior also. When the dam passes across a running stream, they make it convex towards the current; by which it is caused to possess much greater strength, than if it were straight. This dam is usually eleven or twelve feet across at its base, and it is enlarged every year; and it frequently becomes covered with vegetation, so as to form a kind of hedge.

707. When the dam is completed, the community separates into a certain number of families; and the Beavers then employ themselves in constructing huts, or in repairing those of a preceding year. These cabins are built on the margin of the water; they have usually an oval form, and an internal diameter of six or seven feet. Their walls are constructed, like the dam, of branches of trees; and they are covered, on two of their sides, with a coating of mud. Each has two chambers, one above the other, separated by a floor; the upper one serves as the habitation of the Beavers; and the lower one as the magazine for the store of bark, which they lay up for their provision. These chambers have no other opening, than one by which they pass out into the water. It has been said that the flat oval tail of the Beavers serves them as a trowel, and is used by them in laying on the mud of which their erections are partly composed; but it does not appear that they use any other implements, than their incisor teeth and fore-feet. With their strong incisors they cut down the branches, and even the trunks, of trees which may be suitable; and by the aid of their mouths and fore-feet, they drag these from one place to another. When they establish themselves on the banks of a running stream, they cut down trees *above* the point where they intend to construct their dwellings, set them afloat, and, profiting by the current, direct them to the required spot. It is also with their feet that they dig up the earth they require for mortar, from the banks or from the bottom of the water. These operations are executed with extra-

ordinary rapidity, although they are only carried on during the night. When the neighbourhood of Man prevents the Beavers from multiplying to the degree necessary to form such associations, and from possessing the tranquillity which they require for the construction of the works now described, they no longer build huts, but live in excavations in the banks of the water.

708. The building instinct shows itself, even when the Beaver is in captivity, and in circumstances in which it could be of no use. A half-domesticated individual, in the possession of Mr. Broderip, began to build, as soon as it was let out of its cage, and materials were placed in its way. Even when it was only half-grown, it would drag along a large sweeping-brush or warming-pan, grasping the handle with its teeth, so that the load came over its shoulder; and would endeavour to lay this with other materials, in the mode employed by the Beaver when in a state of nature. "The long and large materials were always taken first; and two of the longest were generally laid crosswise, with one of the ends of each touching the wall, and the other ends projecting out into the room. The area formed by the cross-brushes and the wall, he would fill up with hand-brushes, rush-baskets, books, boots, sticks, cloths, dried turf, or anything portable. As the work grew high, he supported himself upon his tail, which propped him up admirably; and he would often, after laying on one of his building materials, sit up over against it, appearing to consider his work, or, as the country people say, 'judge it.' This pause was sometimes followed by changing the position of the material judged; and sometimes it was left in its place. After he had piled up his materials in one part of the room (for he generally chose the same place), he proceeded to wall up the space between the feet of a chest of drawers which stood at a little distance from it, high enough on its legs to make the bottom a roof for him; using for this purpose dried turf and sticks, which he laid very even, and filling up the interstices with bits of coal, hay, cloth, or anything he could pick up. This last place he seemed to appropriate for his dwelling; the former work seemed to be intended for a dam. When he had walled up the space between the feet of the chest

of drawers, he proceeded to carry in sticks, cloths, hay, cotton, &c., and to make a nest; and when he had done, he would sit up under the drawers, and comb himself with the nails of his hind feet."

709. We see, in this account, a very interesting example of the *irrational* character of Instinct. If the animal were guided in its ordinary building operations, by such an amount of *intelligence*, as would lead it to choose and execute its various movements, with a *design* to accomplish certain ends, the same intelligence would direct it to leave these actions unperformed, when the purpose no longer required it; instead of which, we see that the animal is impelled by an internal impulse, to construct erections, as nearly resembling those which it would build up on the banks of its native streams, as the materials and circumstances will permit. Other animals are, in like manner, occasionally conducted by their natural instincts, to the performance of actions equally irrational, and quite incapable of answering the purpose which the particular instinct is destined to serve.

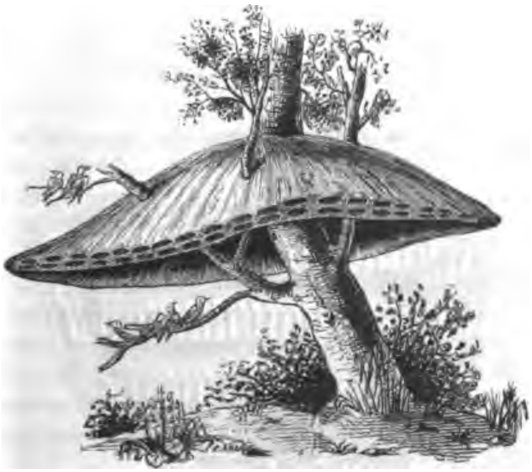

FIG. 266.—NEST OF REPUBLICAN GROSBEAK.

Thus the Hen will sit upon an egg-shaped piece of chalk, as readily as upon her own egg; being deceived without difficulty by the general similarity of its appearance: and the Flesh-fly lays its eggs in the petals of the Carrion-flower, whose odour so much resembles that of tainted meat, as evidently to deceive the Insect into the belief, that it affords the proper receptacle for the eggs.

710. Societies like those of the Beaver are rare among Birds, whose associations are usually less perfect. There is a small species, however, termed the Republican Grosbeak (*Loxia socia*), which lives in numerous societies in the neighbourhood of the Cape of Good Hope, and constructs its nest under a sort of roof which is common to the whole colony (Fig. 266).

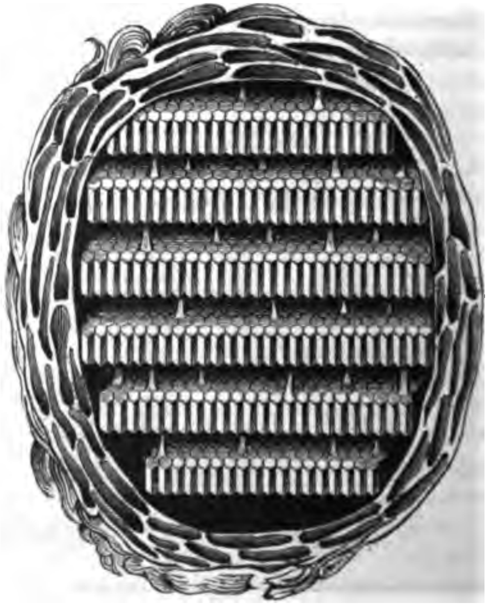

FIG. 267.—NEST OF WASP.

711. It is among Insects, that we find the most remarkable

examples of this kind of social instinct; and the structures which are produced by the united labours of a large number, working together in harmony, are extremely interesting. The nests of Wasps are constructed in this manner. In order to form the materials for building them, these Insects detach with their mandibles the fibres of old wood, which they convert by mastication into a sort of pulp, that hardens into the consistence of pasteboard; of this substance they construct several ranges of hexagonal *cells;* and the *combs* thus formed are arranged parallel to each other at a regular distance, and are united at intervals by little columns which serve to suspend them (Fig. 267). The whole is either hung in the air, lodged in the hollow of a tree, or buried in the ground; and it is sometimes enclosed in a general envelope, sometimes left uncovered, according to the species.

712. The same community of labour is observed in the ordinary Hive-Bees, which present to the intelligent observer a source of interesting occupation that scarcely ever fails. The number and variety of instincts, each of them most perfectly adapted to the end in view, which these Insects exhibit, is most wonderful; and many volumes have been written upon them, without by any means exhausting the subject. Nothing more than a very general sketch of these can be attempted in the present Treatise, for the reason already mentioned; but the illustrations they afford of the general remarks heretofore made upon the nature of Instinct, are too valuable to be passed by. Each Hive contains but a single Queen; and she is the only individual capable of laying eggs. There are usually from 6 to 800 males or Drones; and from 10,000 to 30,000 Neuters or Working-bees. In their natural condition, they live in the hollows of trees; but they appear equally ready to avail themselves of the habitations prepared for them by Man. The cells, of which their combs are composed, are built up of the material that we term *wax.* Of this, a part may be obtained direct from Plants, since it is secreted in greater or less abundance by several species; but there seems

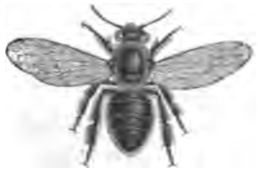

FIG. 268.—WORKING-BEE.

to be no doubt, that Bees can elaborate it for themselves from the saccharine materials of their aliment (§. 155). The wax is separated in little scales, from between the segments of the abdomen; these scales are kneaded together by the mandibles of the Insect, and are then applied to the construction of the cells. It is easy to understand, that the hexagonal form is that which enables the cells to be best adapted to the purposes for which they are built, whilst the least amount of material is expended. As they are intended, not only to contain a store of honey, but also to serve as the residence for the Larvæ and Pupæ, it is evident that their form must approach near to that of the cylinder, in order that there may be the greatest economy of space; but it is also evident that, if their walls were circular, a large quantity of material would be required, to fill up the interspaces left between them; whilst, by giving the cells the hexagonal form, their walls everywhere have the same thickness, and their cavity is sufficiently well adapted to the forms of the larva and grub.

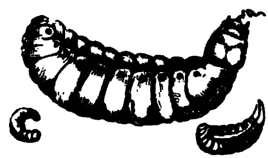
FIG. 269.—LARVÆ OF BEE, NATURAL SIZE, AND MAGNIFIED.

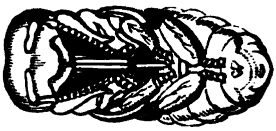
FIG. 270.—PUPA OF BEE.

713. Every comb contains two sets of cells, one opening on each of its faces. The cells of one side are not exactly opposite, however, to those of the other; for the middle of each cell abuts against the point, where the walls of three cells meet on the opposite side; and thus the partition that separates the cells of the opposite sides, is greatly strengthened. This partition is not flat, however, but consists of three planes, which meet each other at a particular angle, so as to make the centre of the cell its deepest part. Of the three planes which form the bottom of each cell, one forms part of the bottom of each of the three cells, against which it abuts on the opposite side, as shown in the accompanying figure. Now it can be proved, by the aid of

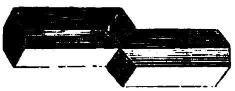
FIG. 271.—HEXAGONAL CELLS, SHOWING THE MANNER OF UNION AT THE BASE.

mathematical calculation of a very high order, that, in order to combine the greatest strength with the least expenditure of material, the angles formed by the edges of these planes should have a certain regular amount; which was ascertained by the measurement of Maraldi to be, for one, 109° 28′, and for the other 70° 32′. By the very intricate mathematical calculations of Koenig, it was determined that the angles should be 109° 26′, and 70° 34′,—a coincidence between the theory of the Mathematician and the practice of the Bee (untaught, save by its Creator), which has been ever regarded as truly marvellous, and as affording one of the most remarkable examples of the operation of instinct. The very small discrepancy, amounting to only 2 minutes of a degree (or 1-10,800th part of the whole circle), has been usually supposed to result from a slight error, in the observation of the angle employed by the Bees; but Lord Brougham, not satisfied with this explanation, has recently applied himself to a fresh mathematical investigation of the question; and he has shown that, owing to the neglect of certain small quantities, the result formerly obtained was erroneous, to the exact amount of 2 minutes; so that the Bees proved to be right, and the Mathematician wrong.*

FIG. 272.—APIARY.

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* See his Supplement to New Edition of Paley's Natural Theology.

714. The ordinary cells of the comb are of two sizes; one for the larvæ of the working-bees, and the other for those of the drones. Both of these may be used for laying up a store of food, either for themselves or the progeny; but it is observed that, in the breeding season, the central portion of each comb, only, is tenanted by the young Bees; this being the part of the hive where they will most constantly obtain the warmth requisite for their development (§. 411). The deposition of the eggs in these cells only, therefore, is another remarkable instinct on the part of the Queen; and this is further manifested in the fact, that she never deposits eggs in the comb, with which the glasses are filled that are sometimes placed on the top of a hive, as in Figure 272. The temperature of these glasses is necessarily lower than that of the interior of the hive.—The royal cells, as they are termed, in which the larvæ of the young queens are reared, are different in form from the rest; sometimes they lie in the midst of them, as shown in the accompanying figure; but most commonly they project from the sides or edges of the comb.

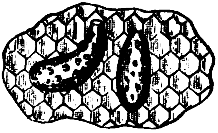
FIG. 273.—ROYAL CELL.

715. The food which the Bees collect, is of two kinds,—the honey of flowers for themselves, and their pollen for the larvæ. The honey, which they suck up by means of their proboscis-like tongue, seems to undergo some change in their digestive cavity; and the part not required for their own nourishment, is afterwards returned from the stomach, and deposited in one of the cells, which, when filled, is *sealed* with a covering of wax. The pollen is obtained by rubbing the body against the anthers, or the parts of the flower over which the pollen may have been scattered by their bursting; and when the surface has been suffi-

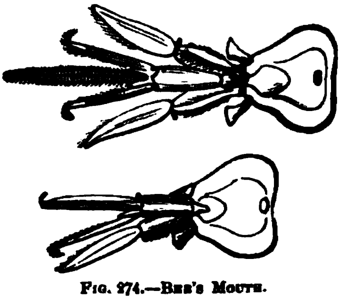
FIG. 274.—BEE'S MOUTH.

ciently *dusted* in this manner, the fine particles are collected from it by little *brushes*, with which the feet of the Bee are furnished, and are worked up into small pellets, which the Insect carries home in basket-shaped hollows, of which there is one on each hind thigh. The pollen or farina thus collected is worked up with honey in a mass, to which the name of bee-bread has been given; and with this the larvæ are nourished, until the time when they are about to pass into the pupa state. The mouth of the cell is then sealed by a waxen cover; and the larva spins a delicate silken cocoon, within which it undergoes its metamorphosis. In the chrysalis state it remains quite inactive for some days; and during the latter part of this period, when it is rapidly approaching the condition of the perfect Insect, its development is aided by the heat supplied by the nurse-bees, which seem prompted by a remarkable instinct to generate it, in the manner formerly described (§. 411).

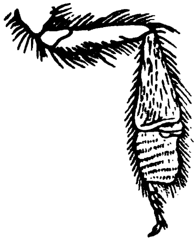

FIG. 275.—HIND LEG OF WORKER.

716. One of the most curious features in the whole economy of Bees, is the manner in which they manufacture new Queens, when, from any cause (as by the intentional removal of her from the hive), their sovereign has been lost. In order to understand the process, it is necessary to be aware, that the ordinary working-bees may be regarded as females, with the reproductive organs undeveloped; and it appears to depend on the manner in which they are treated in the larva state, whether the egg shall be made ultimately to produce a queen or a working-bee. For if, when the queen has been removed, the royal cells (which are usually among the last constructed) be not sufficiently forward, and contain no eggs, the bees select one or more worker-eggs or larvæ, remove the egg or larva on either side of it, and throw the three cells into one. The larva thus promoted is liberally fed with *royal jelly*, a pungent food prepared by the working bees for the exclusive nourishment of the queen-larvæ; and in due time she comes forth a perfect queen. This

change is doubtless owing to the peculiar effect of the food; and it is remarkable that it should operate, not only in developing the reproductive organs, but also in altering the shape of her tongue, jaws, and sting, in depriving her of the power of producing wax, and in obliterating the hollows just referred to, which would otherwise have been formed upon her thighs.

Manifestations of Intelligence.

717. The amount of reasoning power possessed by some among the lower animals, may be considered as very much upon a par with that exhibited by an intelligent child, about the time when it is learning to speak. One of its first exercises is in the connection or *association* of ideas; such as is shown in the following instance, related to the Author by an eye-witness. A Wren built its nest in the slate-quarries at Penrhyn, in such a situation as to be liable to great disturbance from the occasional explosions. It soon, however, learned to quit its nest, and fly to a little distance, on the ringing of the bell which warned the workmen. This was noticed, and was frequently shown to visitors, by ringing the bell when there was not to be an explosion; so that the poor bird suffered many needless alarms. It at last learned, however, that the first notion it had formed, by the association of the ringing of the bell with the explosion, was liable to exceptions; and it formed another more correct. For it was observed after a time, that the wren did not leave its nest, unless the ringing of the bell was followed by the moving away of the workmen. A similar process of association, carried rather further, but still quite simple enough to be readily believed, is shown in two Dogs, which have been taught by their master to play at Dominoes, and which go through the game with another person (under circumstances which render the idea of collusion with their master impossible) with the utmost regularity and correctness; not only playing rightly themselves, but watching to see that their adversary does so too. This, also, is a feat which a very young child might be taught to perform. A third instance has reference to the patient endurance of bodily pain, in opposition to the instinctive tendency to struggle

against the infliction of it, and evidently occasioned by a voluntary effort on the part of the animal, made by it in obedience to the dictates of its reason. Dr. Davy mentions having seen an Elephant, in India, that was suffering under a deep abscess in its back, which it was necessary to lay open, in order to effect a cure. "He was kneeling down, for the convenience of the operator, not tied; his keeper was at his head. He did not flinch, but rather inclined towards the surgeon, uttering a low suppressed groan. He seemed conscious that what was doing was intended for his good; no human being could have behaved better; and so confident were the natives that he would behave as he did, that they never thought of tying him." It were much to be wished, that all human beings would imitate this docile Elephant's self-control. It is sometimes manifested, however, even in Infancy; the painful operation of lancing the gums being often sustained without a cry, from the consciousness of the benefit derived from it.

718. It has been stated that the relative amount of intelligence in different animals, bears a pretty constant proportion to the size and development of the Cerebral hemispheres (§. 452). That *size* alone does not produce the difference, is evident from a number of facts. As we advance from the lower to the higher Vertebrata, we observe a marked advance in the *complexity* of the structure of the brain. Its surface becomes marked by convolutions (§. 456), which greatly increase the surface by which the blood-vessels enter it from the enclosing membranes; and in proportion to the increase in the number and depth of these, do we find an increase in the thickness of the layer of *gray matter*, which seems to be the real centre of all the operations of the organ. The arrangement of the white or fibrous tissue, which forms the interior of the mass, also increases in complexity; and as we ascend from the lower Mammalia up to Man, we trace a great difference in the number of the fibres, which establish communications between different parts of the surface. Still there can be no doubt that the size of the cerebrum, compared with that of the spinal cord and the ganglia at its top, usually affords a tolerably correct measure of the intelligence of the animal; and that,

even in comparing together different Men, we shall find the same rule to hold good, when due allowance has been made for the comparative activity of their general functions, such as is expressed by the word *temperament*. Thus, two men having brains of the same size and general conformation, may differ greatly in mental vigour, because the general system of one performs its functions much more actively and energetically than that of the other. For the same reason, a man of small brain, but whose general habit is active, may have a more powerful mind than another whose brain is much larger, but whose system is inert, his perceptions dull, and his movements languid. But of two men alike in this respect, and having the same general configuration of head, it cannot be doubted that the one with the larger brain will surpass the other. It is a striking fact, that almost all those persons who have been eminent for the amount of their acquirements, or for the influence they have obtained by their talents for command, over their fellow-men, have had large brains; this was the case, for example, with Newton, Cuvier, and Napoleon.

719. The size of the brain, and especially of its anterior lobes (which seem particularly connected with the higher reasoning powers), as compared with that of the face, may be estimated pretty correctly by the measurement of the *facial angle;* as proposed by Camper, an eminent Dutch naturalist. This is done by drawing a horizontal line (*c d*, Figs. 276 and 277), between the entrance to the ear, and the floor of the cavity of the nose, so as to pass in the direction of the base of the skull; this is met by another line (*a b*), which passes from the most prominent part of the forehead to the front of the upper jaw. It is evident that this last will be more inclined to the former, so as to make a more acute angle with it, in proportion as the face is more developed, and the forehead more retreating; whilst it will approach more nearly to a right angle (as in Fig. 276), if the

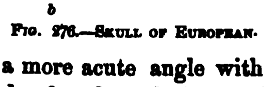

FIG. 276.—SKULL OF EUROPEAN.

forehead be prominent, and the muzzle project but little. Hence this *facial* angle will indicate, with tolerable correctness, the proportion which the brain bears to the face,—the instrument of intelligence, to the receptacle of the organs of sense.

720. Of all animals, there are none in which the facial angle is so open as in Man; and there exist, in this respect, great variations, even among the different human races. Thus, in European heads, the angle is usually about 80° (Fig. 276). The ancient Greeks, in those statues of Deities and Heroes to which they wished to give the appearance of the greatest intellectual power, made it 90°, or even more, by the projection they gave to the forehead. On the other hand, in the Negro races, it is commonly about 70° (Fig. 277); in the different species of the Monkey tribe, it varies from about 65° to 30° (Fig. 278); and as we descend still lower, we find it becoming still more acute. In the Horse and Boar, for example, it becomes impossible to draw a straight line from the forehead to the upper jaw; in consequence of the retreating character of the former, and the projection of the nose; this will be evident from an examination of Fig. 279. In Birds, Reptiles, and Fishes, the facial angle, when it can be measured, is found to be still further diminished.

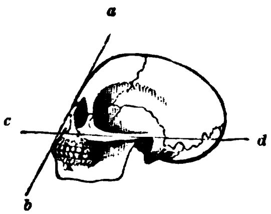

FIG. 277.—SKULL OF NEGRO

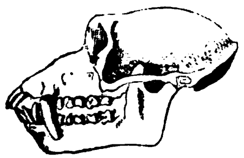

FIG. 278.—SKULL OF MACACUS.

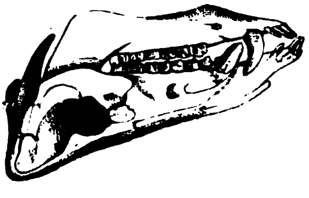

FIG. 279.—SKULL OF BOAR.

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721. It appears, then, that the mind of Man differs from that of the lower animals, rather as to the *degree* in which the

reasoning faculties are developed in him, than by anything peculiar in their *kind*. Among the more sagacious Quadrupeds, it is easy to discover instances of reasoning as close and prolonged, as that which usually takes place in early childhood; and it is only with the advance of age, and the maturity of the powers, that the superiority of Man becomes evident. There is a tendency, however, by which he seems to be distinguished from all other animals;—this is, the disposition to believe in the existence of an unseen but powerful Being, which seems never to be wanting (under some form or other) in any race or nation, although (like other natural tendencies) it may be defective in individuals. Attempts have been made by some travellers to prove that particular nations are destitute of it; but such assertions have been based upon a limited acquaintance with their habits of thought, and with their outward observances: for there are probably none, that do not possess the idea of some invisible Power external to themselves, whose favour they seek, and whose anger they deprecate, by sacrifice and other religious observances. It requires a higher mental cultivation than is commonly to be met with among savage races, to conceive of this Power as having a *spiritual* existence; but it appears, from the reports of Missionaries who have laboured to spread Christianity amongst the Heathen, that an aptitude or readiness to receive this idea is rarely wanting; so that the faculty is obviously present, though it has not been called into operation.

722. Closely connected with this tendency to belief in a Great unseen Power, is the desire to share in His spiritual existence, which seems to have been implanted by the Creator in the mind of Man, and which is one of the chief natural arguments for the immortality of the soul,—since it could scarcely be supposed, that such a desire should have been implanted by our beneficent Maker, if it were not in some way to be gratified. By the Immortal Soul, the existence of which is thus guessed by Man, but of whose presence within him, he derives the strongest evidence from Revelation, Man is connected with beings of a higher order, amongst whom Intelligence exists, unrestrained in its exercise by the imperfections of the bodily frame, with which

it is here connected, and by which it here operates.—Such views tend to show us the true nobility of Man's rational and moral nature; and the mode in which he may most effectually fulfil the ends for which his Creator designed him. We learn from them the evil of yielding to those merely animal tendencies,—those "fleshly lusts which war against the soul,"—that are characteristic of beings so far below him in the scale of existence, and tend to degrade him to their level; and the dignity of those pursuits, which by exercising his intellect, and by expanding and strengthening his loftier moral feelings, raise him towards beings of a higher and purer order. But even the loftiest powers and highest aspirations, of which he is at present capable, may be regarded as but the germs or rudiments of those more exalted faculties, which the human mind shall possess, when, purified from the dross of earthly passions, and expanded into the comprehension of the whole scheme of Creation, the soul of Man shall reflect, without shade or diminution, the full effulgence of the Love and Power of its Maker.

CHAPTER XV

OF REPRODUCTION.

723. There is no one of the functions of living beings, that distinguishes them in a more striking and evident manner from the inert bodies which surround them, than the process of Reproduction. By this function, each *race* of Plants and Animals is perpetuated; whilst the *individuals* composing it successively disappear from the face of the earth, by that death and decay which is the common lot of all. There are some tribes, in which the death of the parent is necessary for the liberation of the germs, from which a new race is to spring up; and there are many in which the life of the parent is not prolonged, after it has laid the foundation (as it were) of a new generation; so that this function can be only exercised once by each individual. But, in general, the mode in which it is performed renders it less injurious to the parent; and indeed it may be regarded as a function equally consistent with its well-being, with any of those we have been considering. A very unnecessary degree of mystery has been spread around this process. It has been regarded as one altogether inscrutable,—whose real nature could not be unveiled, even by the scientific inquirer, and whose secrets the uninitiated should never seek to comprehend. But so much light has been thrown upon it by recent investigations, that we now know at least as much of this, as of almost any other function; and the Author's experience has led him to believe, that such knowledge may be communicated to the general reader, without the least infringement of the purest delicacy of feeling. Indeed his own judgment would lead him to the belief, that the possession of such knowledge is the best possible check to that

curiosity, which almost every one feels upon the subject, and which frequently leads to improper modes of gratifying it.

724. It has been elsewhere shown (VEGET. PHYS. Chaps. IX., XII.), that, in the Vegetable Kingdom, there are two distinct modes, by which the propagation of most kinds of Plants may take place;—the extension of the parent structure into new portions, which are independent of each other, and which can maintain their lives when separated from it;—and the formation of certain bodies, the development of which does not commence, until they have been cast off from the parent,—these being nothing else, from the first, than the germs of new individuals. Now the bodies of the first class are known as *leaf-buds* in the Flowering Plants, and as *gemmæ* among the Cryptogamia; many of which last, as the *Marchantia* (VEGET. PHYS. §. 33) are furnished with a peculiar means of producing them. These buds may be developed in connexion with the parent structure, and may continue to form a part of it; or they may be removed from it (as in the processes of budding, grafting, &c.), and may be developed into new individuals. On the other hand, the bodies of the second class are known as *seeds* among the Flowering Plants, and as *spores* among the Cryptogamia. From the very first, these are destined to produce new individuals; and their development does not take place, until they are cast off from the parent, which frequently (as in *annual* plants) dies as soon as it has matured them and set them free. Both these modes of Reproduction exist in the Animal Kingdom; but the former is confined to its lowest tribes; and among these, we not only find a tendency to multiplication by buds, but an extraordinary power of regenerating lost parts, and even of reproducing the whole structure from a small portion of it.

725. This is the case, to a greater or less degree, in most of the Radiated classes; and in none more than in the *Hydra*, already so frequently referred to. Not only will the body reproduce any of the arms that have been cut off, but, if it be cut up into a number of small portions, each of these will develop itself into a complete polype. Although this interesting little animal appears sometimes to reproduce itself by *ova* or

eggs, yet its usual mode of propagation is by *buds*. From the side of the parent, a little knot or protuberance is seen to project; this increases in size, and assumes more of the form of a young animal; tentacula sprout from around its extremity, and a mouth or opening into its interior cavity is formed there; this cavity, which at first communicates with the stomach of the parent, is gradually shut off from it; the young animal begins to seize and digest its own food, whilst still attached by its base to the body of the parent; and at last the connexion is broken, and it becomes completely independent. Several of these buds, in different stages of development, may sometimes be seen on the body of a well-fed Hydra (as shown on the left-hand side of Fig. 280); and occasionally the young ones themselves begin to produce a third generation, before they are separated from the body of the parent; so that as many as 18 individuals, in various stages of development, have been seen sprouting from a single one. The Sea-Anemone has a power of reproducing lost parts almost equal to that of the Hydra; but it does not propagate itself in the same manner, its reproduction being always effected by ova. But these eggs are not unfrequently hatched, and the embryos partially developed, within the body of the parent; so that the half-formed young ones are ejected from its mouth, along with the undigested remnants of its food (§. 132).

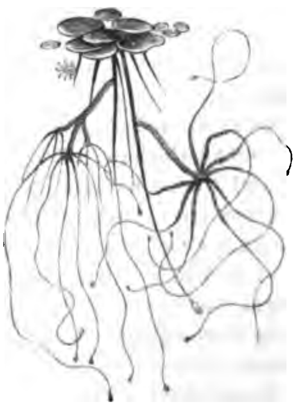

FIG. 280. Hydra, attached to duck-weed.

726. Among the compound Polypifera, we find the process of reproduction by budding carried to a great extent. The buds do not originate, however, from the individual polypes, but from the tree-like structure which connects them (§. 133). This structure has powers of growth in itself, independently of the polypes, which may be regarded as the mouths by which it obtains its food; and when it extends itself, by commencing a

new branch or twig, the polype-cell is first formed, and the polype itself does not appear until this is complete. A small portion of the gelatinous flesh peeled off from the stem of one of the stony corals (§ 133), is able to reproduce the entire structure; for, absorbing nourishment from the surrounding fluid, it begins to deposit stony matter on the surface on which it may be lying, so as to lay the foundation of a cell; within this, a polype is speedily developed; and the stem and branches, with multitudes of new polypes, are in time produced, by the continuance of a similar process.

727. In the *Star-fish*, a considerable power of regenerating lost parts has been observed; but this appears to be confined to the reproduction of the arms from the body. As it does not seem that the body can be regenerated from the arms, or from a half of itself, no multiplication of individuals can take place in this manner; and in this class there is no propagation by buds, as in the group just mentioned. In *Animalcules*, however, we find this process, or a modification of it, to be almost the only means of reproduction, which the beings composing that wonderful group possess; for the greater number of species never deposit eggs, but multiply themselves by the development of buds, or by the division of their own bodies. The former process may be continually witnessed by the microscopic observer, in the common *Vorticella*, a bell-shaped animalcule, attached by a stalk, and abundant in almost every pool in which aquatic vegetables grow, especially clustering around the stems of Duckweed (Fig. 281, *a*, *a*). Its various

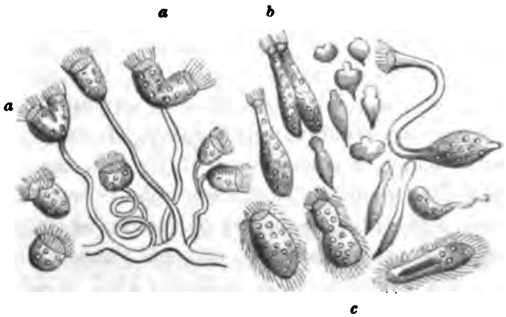

FIG. 281.—VARIOUS FORMS OF ANIMALCULES.

stages closely resemble those, which have been already described in the Hydra. But in many other species, the body of the parent divides into two equal parts, in each of which we see a mouth and other parts resembling those of the original. This division is gradual. A narrowing of the body along or across its middle (for the *fission* or cleaving sometimes takes place lengthways, as at *b*, sometimes transversely, as at *c*), is first seen; the indentation at the edge becomes gradually deeper, and at last the two parts hold together by but a narrow band, which finally breaks, and they become free.

728. But there are some species in which this process is stopped short, as it were, before the final separation; and in this case, a compound animal is gradually formed, by the union of many in one line or surface,—just as several cells remaining adherent together, but having independent powers of life, form the simple stalks of the *bead-mould*, or *yeast-fungus* (VEGET. PHYS. §. 56). Some very remarkable compound structures are thus produced; and among them is one well known to microscopic observers, under the name of the *Volvox*, or *Globe-animalcule*. This is large enough to be discernible to the naked eye, and is a most interesting and beautiful object under the microscope. It appears in the form of a hollow globe with a transparent wall, inclosing other smaller but similar globes. The wall of each sphere is studded all over with minute green points, disposed at regular distances from each other; and when these are examined with a sufficiently high magnifying power, they are seen to be distinct animalcules, closely resembling in structure those which in other species are separate; each having its own cilia, by the vibrations of which, in connection with the rest, the whole mass receives a rolling motion. They seem to be in some degree connected with each other, by means of vessels, which pass along the transparent glassy wall that supports them. The interior globes are young structures of a similar kind, which have had their origin in one of the animalcules of the parent mass. This, by dividing and subdividing, forms a new group of animalcules, which is at first attached to the interior of the wall of the parent structure; but after a time it is separated, and floats in

its cavity; and, when it is mature, it is liberated by the bursting of the walls which inclose it,—the destruction of the parent being thus necessary for the propagation of the race. Not unfrequently, a third generation may be seen within the second, previously to the setting-free of the latter; and, under the brilliant light and high magnifying power of the solar microscope, even a fourth generation has been seen within the third.

729. Among many of the lower Articulata, the segments of the body appear to be capable of producing new individuals; and there are some among the Annelida, whose ordinary propagation is accomplished in this manner. In some species of the *Earth-worm*, the reproductive power appears to be nearly as great as in the Hydra; for a single individual having been divided into twenty-six parts, almost all of them reproduced the head and tail, and became so many new and perfect individuals; and in another experiment, the head of one of these animals was cut off eight times, and reproduced as often. In the *Nais*, one of the marine-worms, the last joint of the body gradually extends, and increases to the size of the rest of the animal; and a separation is made by a narrowing of the preceding joint, which at last divides. Previously to its separation, however, the young one often shoots out a young one from its own last joint, in a similar manner; and three generations have thus been seen united. In some species of *Nereis*, the separation takes place nearer the middle of the body.

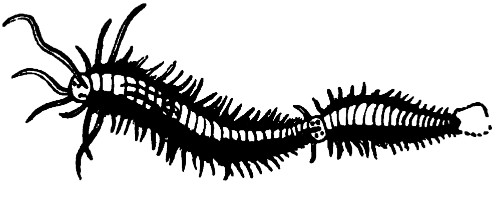

FIG. 282.—NEREIS PROLIFERA.

730. In the *Planaria*,—an aquatic animal, which has the same general structure with the Entozoa (particularly resembling the *Fluke*, common in sheep's livers), but which does not inhabit the bodies of other animals,—the power of reproducing the several

parts of the body is nearly as great as in the Hydra; although it is an animal of much more complex structure, possessing eyes, a regular digestive apparatus with a second orifice, and a system of vessels. A partial division of the body will produce an animal with two heads or two tails, according to the end that is left; portions of different animals, and even of different species, may be grafted together; and in fact any conceivable monstrosity may be produced in this manner. Among the higher Articulata, the power of this kind of reproduction appears to be much less; but it is really not inferior, because the parts regenerated are much more complèx in their structure. Both Crustacea and Spiders have the power of re-forming legs and claws which have been broken off; and in the former class it is very common to meet with individuals, in which the size of the two organs of the same pair is so different, as to show that one of them has been lost and is in process of renewal. Among perfect Insects, whose nutritive functions are for the most part comparatively inactive (§. 105), the reproduction of parts scarcely ever takes place; but many of the Larvæ possess this power in a considerable degree.

731. In the lowest Mollusca, we have some instances of the power of increase by *budding*, which seems so remarkably to connect the Animal and Vegetable kingdoms; but these are restricted to those species, in which, as in Plants, there is an association of a number of individuals into one compound structure (§. 126). In regard to the amount of reproductive power possessed by the higher tribes of this group, few observations have been made; but the head of the *Snail* has been known to be replaced after being cut off, provided the cephalic ganglion is not injured.

732. Even Vertebrated animals exhibit similar phenomena in no inconsiderable degree. In Fishes, this reproductive power is confined to the fins, which are sometimes regenerated after being lost by accident or disease. In many Reptiles, however, especially those of the Frog tribe, it is much more energetic. In the *Salamander*, for instance, new legs, with perfect bones, nerves, muscles, &c., are reproduced, after the loss or severe injury of the original ones; and in the Water Newt, a perfect eye

has been formed, to replace one which had been removed. In the true Lizards, the tail when lost appears to be restored; the new part contains no perfect vertebræ, however, but merely a cartilaginous column like that of the lowest fishes.—In Mammalia in general, as in Man, the power of reproducing entire organs appears to be much less considerable; but each tissue is capable of regenerating that of its own kind; and as this process of renovation is constantly taking place in the living body, the act of Nutrition has been not unjustly spoken of, as a perpetual generation. This power is nowhere, perhaps, more remarkably manifested, than in the re-formation of a whole bone, when the original one has been destroyed by disease. The new bony matter is thrown out, sometimes within, and sometimes around, the dead shaft; and when the latter has been removed, the new structure gradually assumes the regular form, and all the attachments of muscles, ligaments, &c., become as complete as before. A much greater variety and complexity of actions are involved in this process, than in the reproduction of whole parts in the simpler animals; though its effects do not appear so striking. It appears that, in some individuals, this regenerating power is retained to a much greater degree than it is by the class at large; thus, there is a well-authenticated instance, in which a supernumerary thumb on a boy's hand was twice reproduced, after having been removed from the joint. And in many cases in which the crystalline lens of the eye has been removed, in the operation for cataract, it has been afterwards regenerated.

733. We have now to consider the *special* means, by which the proper function of *Reproduction* is performed, in the various tribes of Animals; all the preceding phenomena being referrible to the operations of Nutrition, taking place under peculiar circumstances. In order to understand the real nature of this function, it is simply necessary to recal the statements which have been elsewhere made, respecting its performance in the Vegetable kingdom (VEGET. PHYS., Chap. XII.). In nearly all Plants, we find certain cells appropriated to the development of germs; which, when mature, are set free by the bursting of the parent-cell, and then commence their development into new

cells. These *reproductive cells* (which are themselves usually cast off from the parent structure, before they set free their contained cell-germs,) are termed *spores* in the Cryptogamia, and *pollen-grains* in the Flowering-Plants. The cell-germs contained in the *spore* are developed into cells, without any further assistance, than that which they derive from the air, moisture, &c., that surround them; from these first-formed cells, others are gradually produced; and from them, the various organs of the new plant are gradually developed. But the cell-germs contained in the *pollen-grains* are not thus thrown upon their own resources in the first instance; for they are received into another organ, which supplies them with nourishment already prepared for them by the parent, at the expense of which, their early development takes place. Into this organ, the *ovule*, the cell-germs are conveyed, by a very curious process,—the passage of long tubes put out from the pollen-grain, down the style, and into the ovarium. The germs thus deposited in the ovule, there undergo their early development; and the mature seed contains the embryo or young plant, developed up to a certain point, along with a further supply of nourishment, destined to afford the materials of its growth, until its roots, leaves, &c., are sufficiently advanced, to enable them to perform their proper functions in obtaining and preparing its food.

734. Thus in the higher Plants, we have two sets of organs concerned in the reproductive process;—the *germ-preparing* and the *germ-nourishing*. In the lower, the former alone exist. The aid of the latter is evidently necessary, to enable the young plant ultimately to attain a higher degree of development; for it is a rule which we may trace in universal operation throughout Nature, that, the more highly-organised the being is ultimately to become, the longer does it require assistance in its early development. The two sets of organs are usually possessed by the same individual; so that it requires no aid or influence from another, in the discharge of the Reproductive function. But they are sometimes separated, as in *diœcious* Plants (VEGET. PHYS. §. 435); and the aid of insects or of the wind, and sometimes even the assistance of Man, are needed to convey the germs

contained in the pollen-grains, to the ovules in which their development is to commence.

735. Now in Animals we find, almost without any exception, that the concurrence of these two sets of organs is necessary; so that, even in the lowest tribes, a *germ-preparing* and *germ-nourishing* organ exist; and a body is produced which is analogous to the *seed*, and not to the spore, of Plants. This body is the *ovum*, or *egg;* and it contains, as we shall presently see, with the embryo, a store of nourishment laid up for its support during a longer or shorter time. Such an ovum is produced even by the lowest Radiata, whose mode of reproduction was formerly thought analogous to that of the Cryptogamia. But there is a remarkable difference in the degree of development which the embryo of different tribes attains, at the time of quitting the egg, and coming forth into the world; and to this difference are due, the extraordinary *metamorphoses*, which are exhibited by some, especially among the lower classes.—It is not difficult to understand, why the embryo of *every* Animal should receive such assistance; for it will be remembered as a general principle, that the animal tissues can only be nourished by matter that has previously formed part of a living being (§. 10); and that, as such matter does not exist diffused through water, in a state in which it can be appropriated by the germ (so long as this consists but of a mass of cells), it must be prepared and communicated to the embryo by the parent, or it could not maintain its existence.

736. As the history of the early development of Animals is in many respects parallel with that of Plants, it will be useful to recapitulate the chief phenomena of the latter. The first cells produced from the cell-germs of the Cryptogamia, usually form a row or string, from the sides of which other cells are developed; and in this manner a leaf-like expansion is produced, which has the power of performing the functions of absorption, respiration, digestion, &c., and which, in fact, constitutes the permanent form of the lowest tribes of Plants. But though, in the highest Cryptogamia, the character of the Plant is ultimately to become very different from this, its formation commences in precisely

the same manner; so that the young Fern, which is afterwards to send a woody stem and beautifully-formed leaves into the air, and to transmit its solid roots deep into the ground, might be readily mistaken for an humble Liverwort, whose frond is not destined to raise itself from the ground, but creeps along its surface, and obtains its nourishment by the slight fibres which insinuate themselves into the soil. It is from the *centre* of this leafy expansion, termed the *primary frond*, that the true stem and roots of the Fern are subsequently put forth; and all the remaining portion decays away, as soon as the first true leaf has unfolded itself. Even in the Flowering-Plants, the early development of the embryo takes place upon the same plan; for the mass of cells of which it is composed does not at first take the form which the young plant is afterwards to present, but spreads itself out into the single or double *cotyledon*, which is a leaf-like expansion, closely resembling the primary frond of the Fern. This expansion, absorbs the nourishment provided in the ovule, and prepares it for the development of the young plant, which, even when the seed is mature, forms but a very small proportion of it. The development of the permanent structure takes place rapidly, however, during the process of germination; in which all the nourishment that the seed contains, is prepared for the embryo by the cotyledons, which serve the purpose of leaves, until the stem and roots have been developed, and the true leaves unfolded. When the store has been exhausted, and the development of the embryo has advanced far enough, for it to be able to support itself, the cotyledons decay away.

737. Thus we see that even the highest Plants have to pass through the conditions, which are permanently shown in the lower; and that the parts which are first formed, are destined for a temporary purpose only. We shall find, in tracing the history of the development of Animals, that exactly the same general fact may be observed in even a higher degree,—the number of different stages being greater, and an even larger proportion of the parts first formed in the higher tribes, having only a temporary purpose.

738. The *germ-preparing* organs of Animals differ considerably in their structure, arrangement, and position, in the different classes; and yet as regards their essential character, they are the same in the highest as in the lowest. In the part of the body of the Hydra near its mouth, there are certain cells, within which are produced numerous minute thread-like bodies, which are occasionally set free from it by an opening in its walls, very much in the same manner as the cell-germs of the *Confervæ* are allowed to pass forth (VEGET. PHYS., §. 44); and, as in that tribe, these bodies have a spontaneous motion through the water, which they continue to exhibit for some time. Indeed they have been mistaken for distinct animalcules; but to this character they have no more claim, than have many other parts of the body (for instance, epithelium-cells fringed with cilia), which exhibit similar motions, when detached from the entire structure. Now, although a separate organ, of much complexity of structure, is appropriated in the higher animals to the preparation and expulsion of these germs, its essential portion still consists of *cells;* which are the parts that really form them within themselves, setting them free when mature, by the rupture of their own wall.

739. The *germ-maturing* organs of Animals also differ in their form and arrangement; but in the lowest, they present all the essential parts which they possess in the highest; and we shall therefore draw our description from the former. In certain other cells of the Hydra, near its stem or foot, are developed a set of little bodies, which are analogous in structure to the *ovules* of Plants, being adapted to receive the germs, and to assist them in their early development, by means of the store of nutriment they contain. These ovules also are set free by an aperture which forms, when they are matured, in their containing cell; when they have been fertilised by the introduction of the germ, they become true *ova*, or eggs; and the embryo remains in them, until it is prepared to support its own life,—the period at which it can do this varying considerably in the different tribes.—Now although the structure of the organs in which the ovule is prepared, becomes much more complex in the higher

tribes, its essential character (as in the previous case) remains exactly the same. The ovarium of Birds consists of a mass of dense areolar tissue, in the interstices of which are a vast number of cells, whose function is precisely the same as that of the cells, in which the ovules of the Hydra are developed; for within them are the rudiments of ovules, which are progressively matured and set free by the bursting of the cells. There is this difference, however, in the mode in which they are liberated; that whereas in the Hydra, the ovules, set free by the bursting of the cells, at once pass into the water around, those of the Bird would fall into the cavity of the abdomen, were they not received into the funnel-shaped extremity of a tube, called the *oviduct*, by which they are conveyed to the exterior of the body, to be deposited by the animal in the place selected for it.

740. The essential structure of the ovule or unfertilised egg, as it quits the ovarium, is the same in all animals; and is shown in Fig. 284, A. It consists of a sac, or bag, *d*, containing a fluid, *c*, termed the *yolk;* which is composed of albumen and oil-globules, and in which cells are developed, as the egg becomes ready for fertilisation. The yolk answers precisely the same purpose, in the Animal, as the starchy and oily matter, laid up in the seed, does in the economy of the Plant; being destined to afford support and nourishment to the embryo, until it can obtain these for itself. The yolk contains all the substances which are necessary for the development of the organised framework; and the germ has the wonderful power of appropriating these, in such a manner as to develop itself, from the condition of a simple cell-germ, to that of a highly-organised and most complex fabric. Floating in this fluid is a cell of peculiar aspect, *b*, which is termed the *germinal vesicle;* and upon its walls is a very distinct spot or nucleus, *a*, termed the *germinal spot.* These last parts, have, as we shall presently see, most important functions to perform, in the reception of the germ, and in aiding its early development.

741. In the eggs of Birds, and many others among the higher oviparous animals, we find the yolk-bag surrounded by

a store of pure albumen, commonly termed the *white* of the egg (Fig. 283, *g*), which is gradually absorbed into the yolk-bag, when its own store is exhausted. This is deposited upon its surface, whilst it is passing through the oviduct; and from the lining of this canal seems to be poured out the *liquor sanguinis*, which, by its coagulation, forms the beautiful fibrous membrane, that encloses the white, and is also the basis of the shell (§. 23). This membrane separates into two layers at the large end of the egg; and, enclosed between these, there is a bubble of air, *f*, which serves to give the young bird, just before it is hatched, the power of filling its lungs with air. The yolk-bag floats within the albumen, and always tries to take the highest place, being the lighter of the two; but it is kept nearly to one place, by two cords, which seem formed of peculiarly viscid albumen, and connect the yolk-bag with the lining membrane at the two ends of the shell, *d*, *d*. These are termed the *chalazæ* (*e*, *e*). In this manner, the yolk-bag is always kept at the part of the shell where it can most favourably receive the warmth imparted to it by the mother; and the *cicatricula* or *germ-spot* (which is the mass of cells first developed within the germinal vesicle) is made, by a similar contrivance, always to rise to the highest point.

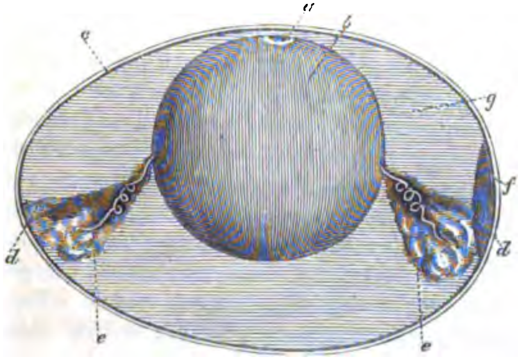

FIG. 283.—SECTION OF A BIRD'S EGG.

a, cicatricula; *b*, yolk-bag; *c*, membrane lining shell; *d*, attachment of chalazæ; *e*, chalazæ; *f*, air space; *g*, albumen.

742. When the ovule is being matured for fertilisation, a remarkable change takes place in the germinal vesicle. Though previously in the centre of the yolk, it now moves up towards one side of it, and becomes flattened against the yolk-bag. At the same time, the edge of its nucleus begins to resolve itself into a ring of cells, which sprout forth, as it were, from its inner wall, into its cavity. These cells enlarge, and another ring is developed nearer the centre of the nucleus, pushing the former one outwards. A third ring is next formed internally to the second; and a similar process continues, until the whole germinal vesicle is filled with minute cells, of which those constituting the outer and first-formed rings are the largest, whilst those forming the central rings are very minute. The centre of the germinal vesicle remains transparent; and into this the germ finds its way, in the process of fertilisation. It is permitted to do so, by the formation of a chink or fissure in the part of the yolk-bag that covers this central point; which fissure closes up again, as soon as the germ has been introduced; and the germinal vesicle then returns to the centre of the yolk-bag. The central transparent space is now seen to be occupied by two new cells, having a very different appearance from the rest; and there can be little doubt that these twin-cells, from which the entire embryo is subsequently to be developed, have had their origin in the germ which has thus entered the germinal vesicle.

743. The two new cells, which have been described as making their appearance, after fertilisation, in the centre of the germinal vesicle, speedily increase in size, and begin to develop new cells in their own interior. At the same time they press upon the cells which filled the germinal vesicle previously to fertilisation; and these gradually liquefy or dissolve away, until all trace of them is lost, and the twin-cells with their offspring are the only ones contained within the germinal vesicle. Here, then, is a remarkable instance of the production of cells for a temporary purpose; and a corresponding process is going on at the same time in the yolk. By comparing these phenomena with others of a similar kind, it can scarcely be doubted that the purpose of this development of *temporary* cells, is (like that of

the floating cells in the chyle and blood) to assimilate or prepare the nourishing matter contained in the yolk and germinal vesicle, for the use of those cells which are to be more *permanent* (§. 241). The cells of the yolk, like those within the germinal vesicle, dissolve away after a certain time, and are no more seen. —A similar process takes place, in the multiplication of every cell produced by the pair, which lays the foundation of the embryo; and in this manner the number is continually multiplied by 2, so that, in place of the single pair of twin-cells, we find successively 4, 8, 16, 32, &c.; and at last a mass is produced, closely resembling a mulberry, in which the number of cells is too great to allow of its being counted. This mulberry-mass is obviously analogous to the collection of cells, which is first developed within the ovule of the Flowering-Plant; and between the condition of the animal and vegetable embryo at this period, there would not seem to be any essential difference.

744. In the next stage, however, a marked difference shows itself, which is very characteristic of the two kingdoms respec-

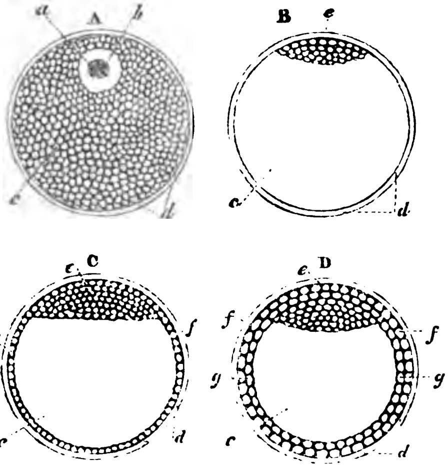

FIG. 284.—A, B, C, D, SUCCESSIVE STAGES IN THE DEVELOPMENT OF THE OVUM. *a*, germinal spot; *b*, germinal vesicle; *c*, yolk; *d*, yolk bag; *e*, mulberry mass flattened; *f*, outer layer of cells forming germinal membrane; *g*, inner layer.

tively. The mass of cells, which is the rudiment of the Vegetable embryo, spreads itself out, as we have seen, into a flat leaf-like expansion, which remains as the permanent form of the lowest plants, but is only temporary in the higher. But in the embryo of the Animal, the mulberry-mass moves up against the side of the yolk-bag (as seen at *e*, Fig. 284, B), and then sends off from its edges a layer of cells, which passes round the yolk, so as completely to enclose it. This layer is shown at *ff*, Fig. 284, C. A second layer, *gg*, is afterwards formed within the preceding; and in the higher animals, a third is subsequently added. These different layers, which are all, in the first instance, composed of cells united together, make up what is termed the *germinal membrane*. Thus the nutriment prepared for the embryo, becomes enclosed in a cavity, from whose lining it is absorbed; and this cavity may be regarded as a stomach, temporary in the higher animals, but permanent in the lower.

745. The development of the Polypes advances but little beyond this point. The covering of the ovum bursts, and the ovum is *hatched* or set at liberty, as soon as the yolk has been completely enclosed by the germinal vesicle. In this state it is termed a *gemmule*; and it swims about freely in water, for some time, by means of *cilia* with which its surface is covered. When it meets with a spot fit for its development, its change into a Polype commences. In the group of which the Hydra is an example, this takes place in the following simple manner. As the yolk is progressively absorbed into the substance of the embryo, the germinal membrane gradually thins away in one point; and at last an aperture is formed, which becomes the mouth. From around this aperture, the tentacula or arms shoot forth; a single row being first formed, and others being afterwards added, in those species in which they are numerous. Thus the two layers of the germinal membrane enter into the *permanent* structure of the animal; the outer one forming the outer integument, the inner becoming the lining of the stomach. In the Hydra and other polypes formed upon its simple plan, these two layers remain united; but in the Sea-Anemone and its allies, they separate from each other at certain points, so that a series of

chambers is formed between them; and these chambers are afterwards set apart for the production of ovules and germs (§. 132).

746. In the higher Animals, on the other hand, the greater part of the germinal membrane, and of the cavity which it forms, have a merely temporary purpose; being cast off, when they have performed their function, like the cotyledons of Plants. It will be convenient to take the development of the Bird's egg as an example of the process, since it occurs near the opposite extremity of the scale. Nearly the whole of the permanent structure of the embryo is formed from a single large cell, which is at first seen in the centre of the mulberry-mass already mentioned, but which presents itself at the surface, when this undergoes the flattening previously described. This cell possesses a large ring-like nucleus, or spot upon its walls; which afterwards becomes lengthened into the shape of a pear, and then into that of a violin. From this nucleus are developed cells, that lay the foundation of the walls of the spinal cord and brain; and a deposition of bony matter in small spots, marking the arches of the vertebræ, soon afterwards takes place. At first these cells merely form a ridge on either side, with a furrow between them; but these ridges gradually rise up and approach one another, and at last meet on the central line, so as to form a complete tube, within which the spinal cord and brain soon begin to be developed.

747. During the progress of this change, another very important one is taking place, which is destined for the nourishment of the embryo during its further development. This is the formation of vessels in the substance of the germinal membrane; which vessels serve to take up the nourishment supplied by the yolk, and to convey it through the tissues of the embryo. The space over which these vessels spread themselves, is called the *Vascular Area;* it makes its appearance during the second day of incubation in the Bird's egg, and soon spreads itself over the surface of the yolk. Islets or points of a dark colour first appear in it; these unite in rows; and at last continuous vessels are formed. The heart makes its appearance at the 27th hour of

incubation, as a simple dilatation of the trunk into which the blood vessels unite (Fig. 286, *h*). Its walls are at first formed by a layer of cells; and no muscular structure is seen in it, until after its regular pulsations have commenced. The mode in which the nourishment of the embryo is imbibed, through the vascular area, from the store laid up in the yolk, bears a striking analogy with that, in which the embryo of the Flowering Plant draws in the store, laid up in its cotyledons or in its albumen. It will be recollected that, in many Dicotyledons, the cotyledons absorb the starchy and oily matter of the albumen into their own substance, *before* the ripening of the seed; so that the seed contains only the embryo and the fleshy cotyledons, the latter of which gradually impart their contents to the former. But in a large number of Dicotyledons, and all Monocotyledons, the albumen remains as a separate store, even when the seed is ripe; and is *afterwards* absorbed by the double or single cotyledon; and imparted to the embryo through its means, as in the Bird's egg. (VEGET. PHYS. §. 440-442). The cells of the germinal membrane in the Animal, and those of the cotyledons in the Plant, probably serve to elaborate or prepare the nourishment, for the use of the germ. It is in the former, that the matter of the yolk is first converted into blood.

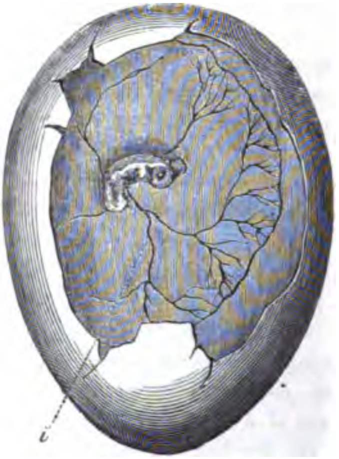

FIG. 285.—EMBRYO OF BIRD, WITH THE VESSELS (*i*) OF THE VASCULAR AREA, AFTER FOUR DAYS' INCUBATION.

748. The germinal membrane surrounding the yolk, may still be regarded as the temporary stomach of the embryo; but instead of the whole of it becoming the permanent digestive cavity, as in the Radiated classes, only a small part of it is retained for this purpose. At about the 25th hour of incu-

bation, its layers begin to exhibit various folds, which afterwards serve for the formation of the various cavities of the body. The parts of it which lie beyond the extremities, and which spread out from the sides of the embryo, are doubled in, so as to make a depression upon the yolk; and their folded edges gradually approach one another under the abdomen, which lies next the interior of the egg. In this manner is formed the permanent digestive cavity; which is at first a simple pouch communicating with the yolk-bag, by a wide opening, as seen at *s*, Fig. 286; but which is gradually separated from it by the narrowing of this orifice (as seen at *s*, Fig. 287), and becomes much more complex in its form. Thus we may say that the digestive cavity in Vertebrata is formed by the pinching-off (as it were) of a small portion of the general sac of the yolk. In the Mammalia, the remainder of the yolk-bag is completely separated from this, by the closure of its narrow orifice; and it is afterwards thrown off; so that only a very small portion of the germinal membrane is received into the permanent structure. But in Birds and other oviparous animals, the whole of the yolk-bag is ultimately drawn into the abdomen of the embryo; the former gradually shrinking, as its contents are exhausted; and the latter enlarging, so as to receive it as a little pouch or appendage. In Fishes, the hatching of the egg very commonly takes place before this process has been completed; so that the little Fish swims about with the yolk-bag hanging from its body.

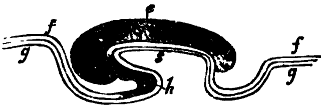

FIG. 286.—FORMATION OF THE DIGESTIVE CAVITY. *e*, embryo; *f*, *g*, layers of germinal membrane; *h*, heart; *s*, stomach.

749. The embryo, like the adult, has need of Respiration; partly that its own heat may be kept up; and partly that the carbonic acid liberated in the various processes of nutrition, may be set free. Owing to the peculiar structure of the membrane covering the albumen and forming the basis of the shell (§. 23), the outer air is enabled to gain access to the interior of the egg; and at first its action upon the blood, whilst circulating in the vascular area, is sufficient. In Fishes, no further provision is

made for this process; since, by the time it would be required, the egg is hatched; the young animal comes forth into the medium it is permanently to inhabit, its own gills come into play, and the air contained in the water can act directly upon the blood circulating in the vascular area. But in the higher oviparous animals, whose development proceeds further before they leave the egg, a special provision is made for this purpose. A bag, termed the *allantois*, sprouts (as it were) from the lower end of the intestine; and gradually enlarges, passing round the embryo, and beneath its enveloping membranes, so as almost completely to enclose it (Fig. 287, *i*). The surface of this bag is plentifully supplied with blood-vessels from the embryo; and as one side of it lies in close proximity with the membrane of the shell, it is very advantageously situated for receiving the influence of the air. It thus serves as the temporary respiratory apparatus of the chick, up to the time when it is preparing to quit the egg.* There is reason to believe that the bird then receives air into its lungs, from the air-space formerly mentioned (§. 741), which increases in size, as the contents of the egg diminish in bulk, by the evaporation of their watery part. By the increased vigour which it thus acquires, it is enabled to perform the movements requisite for extricating itself from its shell; which it does entirely by its own exertions. When it thus becomes independent of the allantois, the circulation through the latter diminishes; and almost the whole sac is separated from the body, by the contraction of the connecting foot-stalk, which at last gives way.

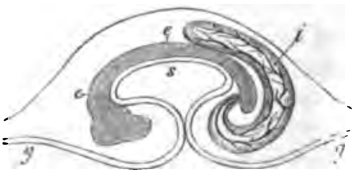

FIG. 287.—Formation of the allantois, *i*. The other references as in Fig. 286.

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* If the respiration of the embryo be prevented, by rendering the shell impermeable to air, its development is completely checked. No means of accomplishing this is so effectual, as smearing the shell with oil or grease of any kind. Hence the effect of the well-known practice of buttering the surface of the egg, in preventing the chick from being reared; and the same operation, if performed when the egg is quite fresh, will preserve it unchanged for some time, its decomposition being prevented by the complete exclusion of the air.

750. In Mammalia, both the yolk-bag and the allantois are superseded, at an early period of the development of the embryo, by a new and remarkable contrivance. The ovum, in passing through the oviduct, receives a new envelope, resembling that which forms the membrane of the shell in Birds; this is termed the *chorion*. It is then received into the cavity of the *uterus*, in which it is delayed for a considerable period, and continually supplied with nourishment drawn from the blood of the parent. From the whole surface of the chorion, a number of little tufts shoot out, which come in contact with the lining membrane of the uterus, and absorb from its vessels a nutritious fluid which they communicate to the embryo. When the allantois is formed, it serves to carry the blood-vessels of the embryo to the inner surface of one part of the chorion; and they shoot through this, and dip down, as it were, into large expanded vessels contained in the walls of the uterus. From the blood of the parent, therefore, the vessels of the embryo are enabled to absorb, through their thin walls, the materials requisite for its growth; but there is no direct communication between the two. The same means serve for the aeration of the blood of the embryo; for this, being brought from its body in the venous condition, is exposed to the influence of the arterial blood of the parent, through the thin walls of its vessels,—just as the venous blood of aquatic animals is aerated in their gill-tufts,—and passes back to the embryo in the arterial condition, having imparted its carbonic acid to the blood of the parent, and received from it oxygen. Thus all but the very early stages of development are performed, in the Mammalia, by means of which we scarcely find a trace in oviparous animals; and, in consequence, the store of yolk prepared in the yolk-bag is very small. But the ovum of Mammalia is originally formed on precisely the same plan with that of oviparous animals; and the first changes which it undergoes are exactly analogous.

751. It would not be consistent with the plan or with the limits of this work, to enter, in more detail, into the consideration of the processes of development; although they present many points of the highest interest. It will be enough to state,

however, that every one of the principal organs in the highest animals, passes through a series of forms, which correspond with those that remain permanent in the lower parts of the scale. Thus the heart, as already stated (§. 747) is at first a simple tube, resembling the dorsal vessel of Insects (§. 293). After a time, this tube is doubled upon itself, and two cavities are formed, an auricle and a ventricle; in this condition, it strongly resembles the heart of the Fish (§. 286): the circulation too is, at an early period, that of the Fish; for the arterial trunk that springs from the ventricle, divides into a set of arches on each side, which exactly resemble the branchial arches of Fishes and Tadpoles. Although no gills are present, yet there is a series of clefts on each side of the neck, passing through to the pharynx; which are analogous to the branchial apertures of the cartilaginous Fishes (§. 317). After a time, however, the auricle and ventricle of the heart are each divided by a vertical partition, so that four cavities are formed, out of the two which previously existed; and at the same period, the arrangement of the vessels undergoes a change, by the division of some trunks, and the obliteration of others, so that they gradually assume the distribution which is characteristic of warm-blooded animals (§. 281). But even up to the time of the birth of the Mammalia, there is a communication between the two sides of the heart, and between the pulmonary and systemic vessels, which is exactly analogous to that which permanently exists in the Crocodile (§. 283).

752. The Unity of Plan, which is visible through the whole Animal Kingdom, is nowhere more remarkable, than in the function of which an outline has now been given. We have seen that, however apparently different, the essential character of the Reproductive process is the same in the highest Animal as in the lowest. It has been shown that the development of the highly-organised body of Man,—which is to serve as the instrument of those exalted faculties, by the right employment of which he is made "but a little lower than the Angels,"—commences from the same starting-point with that of the meanest creature living: for even Man, in all the pride of his philosophy, and all the splendour of his luxury, was once but a single cell, undistinguishable, by all human means of observation, from that which constitutes the entire fabric of one of the simplest Plants. And when the Physiologist is inclined to dwell unduly upon his capacity for penetrating the secrets of Nature, it may be salutary for him to reflect that,—even when he has attained the furthest limits of his Science, by advancing to those general principles, which tend to place it on the elevation which others have already reached,—he yet knows nothing of those wondrous operations, which are the essential parts of every one of those complicated functions, by which the life of the body is sustained. Why one cell should absorb,—why another, that seems exactly to resemble it, should assimilate,—why a third should secrete,—why a fourth should prepare the reproductive germs,—and why, of two germs that seem exactly similar, one should be developed into the simplest Zoophyte, and another into the complex fabric of Man,—are questions that Physiology is not likely ever to answer. All our science is but the investigation of the mode or plan on which the Creator acts; the Power which operates is Infinite, and therefore inscrutable to our limited comprehension. But when Man shall have passed through this embryo state, and shall have undergone that metamorphosis, by which everything whose purpose was temporary shall be thrown aside, and his permanent or immortal essence shall alone remain, then, we are encouraged to believe, his finite mind shall be raised more nearly to the character of the Infinite; all his highest aspirations shall

be gratified, and never-ending sources of delightful contemplation shall be continually opening to his view. The philosopher who has attained the highest summit of mortal wisdom, is he who, if he use his mind aright, has the clearest perception of the limits of human knowledge, and the most earnest desires for the lifting of the veil that separates him from the Unseen. He, then, has the strongest motives for that humility of spirit and purity of heart, without which, we are assured, none shall see God.

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THE END.

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